Status and Future Prospects for the Pacific Ocean Perch Resource in Waters off Washington and Oregon as Assessed in 2000

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Executive Summary

This assessment applies to Pacific ocean perch (*Sebastes alutus*) **(POP)** for the US Vancouver and Columbia area combined. Catches are characterized by large removals during the mid-1960s by foreign vessels. The domestic fishery proceeded with subsequent moderate removals of between 1,000-2,000 tons per year since 1976. Catches have been further reduced by management measures to about 700 tons since 1995. In 1999 the catch was estimated at slightly higher than 500 tons and for 2000, the catches are estimated at slightly less than 300 tons.

Previous assessments were done in 1992 and 1995 and involved extensive analyses of diverse data types using an age structured model (the stock synthesis program). In 1998, and in this assessment, a similar model structure was implemented. The new data presented in this assessment include updated catches, a revised length-at-age transition matrix, updated commercial length frequency data, and the 1998 NMFS triennial-trawl survey estimate of biomass and age structure. There were a number of changes in model structure from that used in the 1998 assessment. A non-informative prior was placed on steepness and a very diffuse prior was placed on the trawl survey catchability estimates reflecting the lack of relevant auxiliary information. Also the population was not assumed to be at equilibrium at the start of the fishery and that the stock size at the beginning of the fishery (1956) was consistent with the variability that might be expected based on observed recruitment variability.

As in past assessments, the estimates of current stock status are uncertain and conditional on assumptions about the data and the model. The 1998 survey age composition data provides the first information of year class strengths observed in the 1990s (age composition was not determined for the 1995 survey) and there is evidence of three “strong” year classes. These values are not well determined, but show some promise of improved stock status. In this assessment, a wide range of models was evaluated to present a clearer depiction of the model structure and how the data are providing insight on stock condition. This involved running three distinct types of models. These were simply 1) an age-structured production model (with no recruitment stochasticity), 2) an age-structured model with no underlying estimate of productivity model, and 3) an age-structured production model with recruitment stochasticity. We evaluated these 3 models (and variants) with respect to implications regarding trawl survey catchabilities. These catchabilities are shown to be negatively correlated with productivity estimates. We evaluate the sensitivity of model results to assumptions about prior distributions on stock-recruitment parameters.

A number of sources of uncertainty complicate the scientific interpretation of the results presented here. We attempt to develop a model that encompasses greater realism in this

uncertainty. For example, we allow for uncertainty in natural mortality, total catch (by weight) estimates, the spawning biomass and recruitment relationship, and in the survey catchability coefficients. For sensitivity analyses, other plausible alternatives suggest that the overall uncertainty may be greater than that predicted by a single model specification. Nonetheless, we propose that the reference case selected adequately envelops the range of uncertainty.

It is likely that the current management plan (i.e., bycatch only) is not conducive to accurate estimates of removals from the fishery. This assessment relies heavily on the accuracy of removals from the fishery. Accurate estimates of landings and unaccounted fishing mortality (e.g., discard mortality) are crucial to the assessment of the fishery and the subsequent derivation of management reference points. Underestimation of removals, associated with lack of trends in the survey indices, is likely to lead to an overly pessimistic assessment of the fishery.

The recruitment pattern for POP is similar to many rockfish species. Recent decades have provided rather poor year-classes compared to the 1950s and 1960s. This assessment is the first to have new information on POP recruitment in the 1990s. POP otolith samples from the 1995 NMFS survey had not been aged for previous assessment. Given limited resources to age samples, we chose to have the 1998 survey otoliths read for age determinations.

The exploitation status of POP continues to be set to bycatch only. Since POP are at the southern limit of their geographical range, while the overall species condition has improved in other areas more central to their range (e.g., in the Canadian EEZ and in the Gulf of Alaska). Management actions of setting harvest guidelines to bycatch only (ABC=0) implemented over the past several years has not yet resulted in observable stock increases based on available data.

Forecasts for the next three years under an F_{msy} policy and for $F_{50\%}$ harvest rates are very similar and are as follows:

Year	$F_{50\%}$	F_{msy}
2001	831	834
2002	877	880
2003	918	921

Our findings suggest that there is some probability (~15%) that the current stock level is below 50% of the target (B_{msy}) stock size. Based on these results, we recommend harvests should remain at minimal levels until substantive stock increases are observed.

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1.1. Introduction

In 1981 the Pacific Fishery Management Council (PFMC) adopted a 20-year plan to rebuild the depleted Pacific ocean perch (*Sebastes alutus*) resource in waters off the Washington and Oregon coast. This plan was based on the results of two studies. The first study employed a cohort analysis of 1966-76 catch and age composition data as a basis for examining various schedules of rebuilding (Gunderson 1979). This report was later updated with four additional years of catch and age information (Gunderson 1981). The second study provided an evaluation of alternative trip limits as a management tool for the Pacific ocean perch fishery (Tagart et al. 1980). Trip limits are now used by the Council as a means of curbing directed Pacific ocean perch fishing.

In this assessment, we have combined the Pacific ocean perch stocks from the INPFC Columbia region with the US-Vancouver area. Traditionally, distinction between these stocks was based on the size distribution and perceived differences in growth. Examination of size composition for these areas indicates, however, that good recruitment years coincided. Genetic studies of the stock structure suggest mixing of the breeding stock between the INPFC areas (Wishard et al. 1980 Seeb and Gunderson 1988.). Examination of the along-shore catch rate distribution of Pacific ocean perch during the surveys did not reveal substantial gaps which might indicate the need for separate management stocks. Parallel recruitment patterns, genetic similarities, and catch rate distributions suggest that the Pacific ocean perch along the west coast of the US may be from a single stock. If separate stocks do exist, a biological basis for splitting them has not been established. Local “pockets” of relatively isolated Pacific ocean perch probably do exist (D. Gunderson, pers. comm.) hence we recommend that management actions on a coast-wide stock should account for problems of effort concentration and to distribute the catch more evenly.

Prior to 1965, the Pacific ocean perch resource in the US-Vancouver and Columbia areas (Fig. 1) of the International North Pacific Fisheries Commission (INPFC) were harvested almost entirely by Canadian and United States vessels. Most of these vessels were of multi-purpose design used in other fisheries (e.g., salmon and herring) when not engaged in the groundfish fishery (Forrester et al. 1978). Generally under 200 gross tons and less than 33 meters (m) in length, these vessels had very little at-sea processing capabilities. Characteristics that, for the most part, restricted the distance the vessels could fish from home ports and limited the size of their landings. Landings from 1956 to 1964 averaged 2,018 and 1,980 metric tons (t) in the Vancouver and Columbia areas, respectively.

Catches increased dramatically after 1964 with the introduction of large distant-water fishing fleets from the Soviet Union and Japan. Both nations employed large factory stern trawlers as their primary method for harvesting Pacific ocean perch. These vessels generally operated independently by processing and freezing their own catch, and the use of support vessels (e.g., refrigerated transports, oil tankers, supply ships, etc.) permitted the large stern trawlers to operate at sea for extended periods of time. Peak removals by all nations combined amounted to 16,358 t from the Vancouver area in 1966 and 23,976 t from the Columbia area one year later in 1967.

Immediately following these peak years, catches declined very rapidly. By 1969, the Pacific ocean perch stocks were severely depleted throughout the Oregon-Vancouver Island region

(Gunderson 1977). Harvests over the period 1978-1994 averaged 474 t and 833 t in the U.S-Vancouver and Columbia areas, respectively. Landings for the combined region have continued to decline. Catches since 1979, however, have been restricted by the Pacific Fishery Management Council to promote rebuilding of the depleted stocks.

1.1.1. Removals and regulations

Prior to 1977, Pacific ocean perch stocks in the northeast Pacific were managed by the Canadian government in its waters and by the individual states in waters off the United States. With implementation of the Magnuson Fishery Conservation and Management Act (MFCMA) in 1977, primary responsibility for management of groundfish stocks off Washington, Oregon, and California shifted from the states to the Pacific Fishery Management Council (PFMC). At that time, however, a fishery management plan (FMP) for the west coast groundfish stocks had not yet been approved. In the interim, the state agencies worked with the Council to address conservation issues. Specifically, in 1981 the Council adopted a management strategy to rebuild the depleted Pacific ocean perch stocks to levels which would produce maximum sustainable yields within 20 years. On the basis of a cohort analysis (Gunderson 1979) the Council set acceptable biological catch (ABC) levels at 600 t for the US portion of the INPFC Vancouver area and 950 t for the Columbia area. To implement this strategy, the states of Oregon and Washington established landing limits for Pacific ocean perch caught in their waters. Trip limits have remained in effect to this day (Table 1).

1.1.2. Past assessment methods

The condition of Pacific ocean perch stocks off British Columbia, Washington and Oregon have been assessed periodically since the intense pulse of exploitation in 1966-68. The mean exploitable biomass in the Vancouver area during 1966-1968 was estimated at about 34,000 t (Westrheim et al. 1972). Following the years of heavy fishing, catch-per-unit-of-effort (CPUE) for the Washington-based fleet in the Vancouver area dropped to 55% of the 1966-68 levels, indicating a decrease in biomass to 18,700 t during 1969-71 (Technical Subcommittee 1972). Catch rates declined further during 1972-74 which indicated a reduction in biomass by about 11% (Gunderson et al. 1977). The mean weighted CPUE rose slightly in the period from 1975-77 (Fraidenburg et al.1978), however, this may be due to improvements in gear efficiency (the use of "high rise" trawl nets).

Columbia area biomass estimates since 1966 have been calculated by dividing landings by estimated exploitation rates. The mean biomass estimates declined from 23,000 t during 1966-68 to 7,300 t during 1969-72 and 4,300 t during 1973-74 (Gunderson et al. 1977). An area-swept extrapolation from commercial CPUE data in the Columbia area resulted in a biomass estimate of between 8,000 and 9,600 t in 1977 (Fraidenburg et al. 1978). Since the commercial fishery operates mainly in areas of high abundance, these estimates are likely to be biased toward the high side.

Research surveys have been used to provide fishery independent assessments of the abundance, distribution, and biological characteristics of Pacific ocean perch. A coast-wide survey of the rockfish resource was conducted in 1977 (Gunderson and Sample 1980) with the objective of defining the distribution and measuring the abundance of the major species taken in bottom trawls. The 1977 coast wide survey has since been repeated every three years, yielding seven fishery independent assessments of the resource in 1980, 1983, 1986, 1989, 1992, 1995, and 1998. The inter-annual variability of these survey estimates is substantial and given the large amount of sampling error within each year, depicting trends from the estimates alone is inappropriate unless a formal time-series approach is used (e.g., Pennington 1985). The values of the survey estimates and the associated errors are modeled with several other data types as presented below. This improves our ability to assess population trends by taking into account the biology of the species and the fisheries involved in their harvest.

The relative imprecision of biomass estimates derived for Pacific ocean perch from the 1977 rockfish survey prompted requests from the fishing industry and resource managers for closer attention to the status of this resource. In response, the National Marine Fisheries Service (NMFS) coordinated a cooperative research survey of the Pacific ocean perch stocks off Washington and Oregon with the Washington Department of Fisheries and the Oregon Department of Fish and Wildlife in March-May 1979 (Wilkins and Golden 1983). This survey provided more precise biomass estimates indicating stock sizes similar to those calculated from the 1977 triennial survey. Another Pacific ocean perch survey was conducted in 1985 to determine what impact six years of restrictive catch regulations have had on the status of these stocks. Due to the directed effort of the 1979 and 1985 surveys to focus on Pacific ocean perch (and other rockfish species) these have been previously considered as estimates of absolute abundance whereas the triennial surveys have been used as relative abundance indices. In the current assessment, both surveys are modeled as relative abundance indices.

In the 1992 and 1995 assessment documents, the population dynamics of Pacific ocean perch in the US-Vancouver and Columbia areas combined were examined using a statistical age-structured model (Methot 1990). The current model implementation is based on the work of (Fournier and Archibald 1982 and more recently Methot 1997 and Tagart *et al.* 1997). As in past years, the concept of the estimation is to simulate the population through a process model, then evaluate the simulation according observations. The observation model includes the types of errors that occur due to sampling, biomass estimates, CPUE indices, and ageing error. The following presents the information used to set up and run the estimation procedure.

1.2. Data

1.2.1. Fisheries

Catch history

The Pacific ocean perch fishery off the west coast the continental United States experienced extremely high catches during the late 1960's. Prior to 1965, Canadian and United States vessels in the Vancouver and Columbia areas harvested this resource. In 1965, however, foreign vessels (mainly trawlers from the Soviet Union and Japan) began intense harvesting operations for Pacific ocean perch in the Vancouver area, and one year later, entered the Columbia area. During the period from 1966 to 1975, the foreign fleets accounted for the bulk of the Pacific ocean perch removals (Fig. 2). The foreign fishery for Pacific ocean perch ended in 1977. Removals since 1979 have been restricted by the Pacific Fishery Management Council to promote the rebuilding of this resource. Estimated harvest by areas show that the Columbia area represented a large portion of catches through the 1980s and more recently the catch estimates are more evenly split between the US-Vancouver and Columbia areas. The total catch estimates based on the PACFIN database indicates some slight differences with the catch estimates used in previous assessments (Fig 3). Historical catches by domestic and foreign vessels are given in Table 2.

Size and age composition

Gunderson (1981) compiled fishery age composition data for the Vancouver and Columbia INPFC areas. A similar pattern in year-class strength was evident between these areas suggesting that recruitment processes were the same. While the patterns of recruitment appear similar, the magnitudes of year-class strength varied between areas. To keep our model and presentation simple, and since the fisheries operating in both regions share many similarities, we combined the data from both areas (Table 3).

The age composition estimates from the fishery data were estimated by the otolith surface ageing technique. This method counts the number of annual bands apparent on the surface of the otolith. The bias pattern is such that at about age 15 and older, Pacific ocean perch ages tend to be under-estimated. Fish younger than 15 years age appear to be unbiased using the surface ageing method. For this reason we aggregate age 15 years and older to avoid biases.

Annual estimates of length composition from the commercial fishery were also available and used in the model as a surrogate for age. Length data were available from the Oregon Department of Fisheries and Wildlife (1983-91, 1994-1998) and from the Washington Department of Fisheries (1968-1988, 1994-1998). We only used length data in years where age data were unavailable.

CPUE Data

Catch per unit effort (CPUE) data from the domestic fishery (Gunderson 1977) were combined for the INPFC Vancouver and Columbia areas (Fig. 4). While these data reflect catch rates for the US fleet, the highest catch rates coincided with the largest removals by the foreign fleet. This suggests that, barring unaccounted changes in fishing efficiency during this period, the level of abundance during this time was high. For sensitivity analyses, we examine the effect of excluding these data from the model.

Recent logbook information is available for the different regions along the Pacific coast. A description of this data and a preliminary analysis was provided in Ianelli and Zimmerman (1998). Due to the nature of these fisheries it is unclear what, if any, relationship the catch per unit effort data will have with population abundance. For this reason this data was not considered in the current assessment.

1.2.2. Surveys

NMFS Cruises

The survey design used for the 1985 POP survey was similar to that used in 1979 (Wilkins and Golden 1983), but was standardized to correct inconsistencies that arose during the 1979 fieldwork. The two most serious inconsistencies involved the use of three different trawls by four different vessels and variable depth coverage (165-475 m off Washington and 165-420 m off Oregon). The 1985 survey was designed to correct these inconsistencies and to compensate for the differences between the two surveys.

Sampling was done with the same style trawl net (Noreastern) in all areas. In the southern part of the Columbia area (Fig. 1), which had been sampled exclusively with the Mystic trawl in 1979, half of the stations were sampled with the Noreastern and half with the Mystic. The relative fishing power of the two nets was used to adjust Noreastern trawl catch rates in that area to the fishing efficiency of the Mystic trawl. In this way we were able to calculate abundance in the southern most subarea based on Mystic catch rates for comparison with 1979 results. No attempt was made to adjust fishing powers in the Columbia Middle area although a modified 400 eastern trawl was used there in 1979 and the Noreastern trawl was used in 1985. In calculating the 1985 Columbia South area abundance and size composition estimates for comparison with the 1979 results, hauls deeper than 420 m in the Columbia Middle and South subareas were excluded from the data to conform with the 1979 depth coverage. Standardization of the survey design had no effect on the survey pattern in the Vancouver or Columbia North areas.

Length frequency distributions and age compositions from all the surveys are presented in the results section showing model fits (i.e., Figs. 14 & 15, respectively). Since 1985, the age compositions were determined using the break-and-burn method. This method is considered to provide accurate ages (Chilton and Beamish 1982). Survey age composition is available for the 1998 survey but not the 1995 survey. This was selected due to the availability and of resources to age these samples. The available survey age composition data used in the model are presented in Table 4.

The biomass estimates and the standard errors used in the model runs treated the rockfish and triennial surveys both as indices of Pacific ocean perch abundance (Tables 5 and 6). This differs from previous assessments where the rockfish abundance series was treated as an absolute abundance index. The time series of these surveys combined are presented in Fig. 5.

Soviet surveys

The NMFS Alaska Fisheries Science Center developed a historical database of Soviet survey efforts that took place within the US EEZ during the period 1953-1978. These data have not been further examined since the previous assessment. A description of the survey was provided in Ianelli and Zimmerman (1998) and is not repeated here.

1.2.3. Biology and life history

Natural mortality, longevity, and age at recruitment

Assessments of Pacific ocean perch have significantly changed in the past decade because of improved methods of age determination. Previously, Pacific ocean perch age determinations were done using scales and surface readings from otoliths. These gave estimates of mortality of about 0.15 and longevity of about 30 years (Gunderson 1977). Based on the now accepted break and burn method of age determination using otoliths, Chilton and Beamish (1982) determined the maximum age of *S. alutus* to be 90 years. Using similar information, Archibald et al. (1981) concluded that natural mortality for Pacific ocean perch should be on the order of 0.05. Hoenig's (1983) relationship estimates that if Pacific ocean perch longevity is between 70 and 90 yr (Beamish 1979, Chilton and Beamish 1982), M would be 0.059 and 0.046, respectively. In previous assessments (Ianelli *et al.* 1992, 1995) we fixed M at 0.05. In the present analyses we broaden the definition of M and provide a "prior" distribution. Essentially, this acknowledges that we have a fair amount of uncertainty in the overall value of M while keeping its value within a reasonable range (McAllister and Ianelli 1996).

Sex ratio, maturation, and fecundity

Survey data indicated that sex ratios were different between INPFC areas (Ito et al. (1987). These differences were minor (within 5% of 1:1) so for the purpose of this study, we assumed a sex ratio of 1:1 by number. For the 1995 assessment, maturity at size were based on a total 400 female Pacific ocean perch visually examined during the 1986, 1989, and 1992 triennial surveys. Recently, the reliance of maturation studies using visual inspections has been questioned. Histological examinations have found that visual examinations can be biased. For this reason we selected to use age 10 as an estimate for when 50% of POP become sexually mature based on Heifetz *et al.* (1997). As part of a sensitivity analyses, we ran the model with a younger age-at-sexual maturity for comparison.

Length-weight relationship

The length weight relationship for Pacific ocean perch was estimated using survey data collected from the west coast surveys from 1977 to 1989. Estimates from the 593 samples provided the following relationship:

$$W(L) = 9.82 \times 10^{-6} L^{3.1265}$$

where L = length in cm, W = weight in grams. The mean weights at age were computed from the length at age data and then used in the model.

Length at age

Previous age-length relationships were based on age data presented in Gunderson (1981). Using data collected from trawl surveys during 1977-1989 these relationships were estimated for Pacific ocean perch off the Oregon and Washington coast (Ianelli et al. 1992). The length-age matrix used by Ianelli and Zimmerman (1998) was based upon survey and commercial age samples (combined sexes, 5,197 samples). This year, a decision was made to only use survey age samples (including the 1998 survey) that had been aged using the break and burn method (combined sexes 2,855 samples). The fitted von Bertalanffy growth model was thus:

$$L_j = \theta_1 + \frac{(\theta_2 - \theta_1)(1 - k^{j-a_1})}{1 - k^{a_2 - a_1}}$$

where

θ_1=average length of "young" age class (22.22142)
θ_2=average length of "old" age class (39.986)
a_1=age of "young" age class (3 years)
a_2=age of "old" age class (25 years)
k = growth rate (0.82389)

where L_j is the length (cm) at age j in years and the estimated values are given in parentheses.

1.3. Model description

For this assessment a forward projection age-structured model was developed similar to that of Methot (1990) and Tagart et al. (1997). The model equations, parameter descriptions and likelihood formulations are given in Tables 8 and 9.

As mentioned above, we selected a prior distribution for natural mortality instead of assuming a constant fixed value. Also, we allow selectivity to be a smooth function of age and to vary over time. We assume further that the catchability coefficient for NMFS area-swept biomass estimates may be different than 1.0. Here we provide a distribution about this value to acknowledge greater uncertainty in this value than has been done in the past. A vague prior (i.e., relatively flat) distribution for catchability was constructed based on the consideration of a large meta-analysis of trawl survey catchability estimates (Harley et al. 2000). For some cases presented below (Models 1 and 1c) we used a lognormal distribution with a mode of 0.8 and a mean of 1.08. For others (Models 1b and 1d) we used a "less informative" lognormal with model of 0.5 and a mean of 1. This provided a much higher prior probability for low estimates of catchability than that used in the last assessment (Fig. 6).

Finally, we re-parameterized the Beverton-Holt stock-recruitment model so that the critical shape parameter has an easier biological interpretation. We begin with:

$$R_i = \frac{S_{i-3}e^{\zeta_i}}{\alpha + \beta S_{i-3}}$$

$$\zeta_i = \rho\zeta_{i-1} + \sqrt{1-\rho^2}\omega_i, \qquad \omega_i \sim N\left(0,\sigma_R^2\right)$$

where

R_i is recruitment at age 3 in year i,

S_i is the female spawning biomass in year i,

ζ_i is the correlated recruitment anomaly for year i,

α, β are stock-recruitment function parameters.

Values for the stock-recruitment function parameters α and β are calculated from the values of R_0 (the number of 0-year-olds in the absence of exploitation and recruitment variability) and the "steepness" of the stock-recruit relationship (h). The "steepness" is the fraction of R_0 to be expected (in the absence of recruitment variability) when the mature biomass is reduced to 20% of its pristine level (Francis 1992), so that:

$$\alpha = \tilde{B}_0 \frac{1-h}{4h}$$
$$\beta = \frac{5h-1}{4hR_0}$$

where

$\tilde{B}_0$ is the total egg production (or proxy, e.g., female spawning biomass) in the absence of exploitation (and recruitment variability) expressed as a fraction of R_0.

Some interpretation and further explanation follows. For steepness equal 0.2, then recruits are a linear function of spawning biomass (implying no surplus production). For steepness equal to 1.0, then recruitment is constant for all levels of spawning stock size.

We include a stock-recruitment curve as an integrated part of the assessment. Therefore, assumptions about prior parameter values are critical, particularly if the data are non-informative. This feature also allows for computation of F_{msy} values and related quantities such as MSY, B_{msy} etc. The method we develop for this is described in Ianelli and Zimmerman (1998).

Since one important criticism of Ianelli and Zimmerman's (1998) assessment was the informative prior they used on steepness, we selected a less informative prior distribution for this assessment. Initially we assumed to be uniform within the range 0.2-1.0. For reasons that became clear during the preliminary presentations of this assessment (i.e., treatment of survey catchability coefficients) the STAR panel suggested that we use a more informative prior. We used results from Dorn's (2000) hierarchical meta-analysis of rockfish steepness. We selected a Beta distribution from Dorn's combined analyses (using Beverton-Holt and Ricker forms for the stock-recruitment relationship) as our prior on steepness (Fig. 7). We use this prior distribution in Models 1c & 1e presented below. Preliminary analyses showed that the point estimates from the model are insensitive to the use of this prior distribution, but that when doing the full Monte Carlo Markov Chain integration methods (MCMC; Gilkes *et al.* 1996; Gelman *et al.* 1995) runs over all parameter uncertainty, the prior had a significant impact, particularly at the extreme parts of the of the distributions (e.g., where steepness (h) approaches 1.0).

Additionally, the STAR panel requested a sensitivity analysis using a Ricker stock-recruitment curve. To make this comparison we used the parameterization of Kimura (1990):

$$R_i = \frac{S_{i-3} e^{a\left(1-\frac{S_{i-3}}{\varphi_0 R_0}\right)\zeta_i}}{\varphi_0}.$$

The Ricker parameter a maps to steepness as:

$$h = \frac{e^a}{e^a + 4}$$

so that the prior used on h can be implemented in both stock-recruitment forms. Here the term φ_0 represents the equilibrium unfished spawning biomass per-recruit. This sensitivity is presented as Model 1e below. Biological arguments for using a Ricker curve are limited since it is unlikely that cannibalism or habitat limitations decrease pre-recruit survival at high spawning biomass levels.

Analyses of model uncertainty were done three ways. First, for all parameters of interest, approximate variances were computed through the propagation-of-error techniques also known as the Delta method. This method provides an easily computed measure of relative uncertainty among different model parameters but requires assumptions about the shape of the likelihood surface that may be inappropriate. Namely, for the Delta method variance estimates (and those derived from inversion of the Hessian matrix) require that the likelihood surface is quadratic—a condition that holds when the parameters can be shown to be multivariate normally-distributed. To avoid these problems, we performed a Markov-Chain Monte Carlo integration procedure to sample from the "true" posterior probability distribution. This accounts for possible curvature in the likelihood surface amongst parameters and integrates out uncertainty in all dimensions (as opposed to conditional upon, say, maximum likelihood estimates of other so-called "nuisance" parameters). These methods are described in Gilks *et al.* 1996 and in Gelman *et al.* (1996).

Issues of model convergence were assessed a number of ways. First, the Hessian matrix was inverted for all model runs to ensure that it was positive definite (an indication of a poorly converged or over-parameterized model). Second, the estimation was always begun at starting values far from the final solution. Finally, the estimation was carried out in a number of phases. This averts problems where highly non-linear models (such as that used here) enter biologically unreasonable regions (e.g., stock sizes smaller than total catch or stock sizes several orders of magnitude too high).

We evaluated the effect of discards in past assessments. Briefly, Pikitch et al. (1987) reported that the estimated discard rate of Pacific ocean perch, based on observer data during 1985-1987, was largely a function of trip limit regulations. As trip limits were reduced, the discard rate increased. Furthermore, lower trip limits increased the proportion of unmarketable (small) fish that were discarded. The actual catch of Pacific ocean perch off the west coast is not accurately known, in part, due to the lack of information on fish not retained.

The fact that some Pacific ocean perch are being discarded warrants consideration since the current stock level appears to be low and the harvest rates potentially high, even though the species is caught only as bycatch in other fisheries. Previously, a 16% discard fraction was assumed for the recent fishery time period.

We evaluated a range of alternatives to evaluate the relationship of model structure and data to stock condition. This involved running three distinct types of models. These were simply 1) an age-structured stochastic production model, 2) an age-structured model with no underlying estimate of productivity model, and 3) an age-structured production model without recruitment stochasticity. We evaluated these 3 models (and variants) with respect to implications regarding trawl survey catchabilities. We show that the survey catchability is negatively correlated with stock size and stock productivity estimates. In all applicable cases, no prior information on the stock-recruitment relationship was included.

1.4. Results

1.4.1. Model evaluation

Initial apriori model selection (Model 1b specification) was characterized by modifications from the 1998 version (Ianelli and Zimmerman 1998). These modifications included removing the prior distribution placed on the stock-recruitment relationship and having a more diffuse prior distribution on survey catchability, and by allowing for autocorrelation in the recruitment residuals (e.g., Ianelli 2000). This configuration suggested that the survey catchability was about 25% lower ($q \approx 0.18$ versus $q \approx 0.24$). We illustrate this further by profiling different fixed values of q and observe that the approximate upper and lower confidence bounds represent approximately 4-fold difference in abundance (Fig. 8). In addition to abundance, the profile also reveals how natural mortality and the critical stock-recruitment parameter (steepness) are inversely correlated (Fig. 9). Closer examination of the individual likelihood components showed that the fitting of the stock-recruitment curve was the key component driving the catchability to low values. While one could make sound biological arguments to defend this property, we were uncomfortable with this aspect of the model specification. To remedy this situation, we chose two approaches. One approach was to simply reduce the variance on the prior distribution for survey catchability (e.g., Fig. 6). This retains the needed information on stock productivity and improves our intuition about the sampling abilities of NMFS survey gear. The second option was to completely omit the effect of fitting the stock-recruitment curve (i.e., rendering the model similar to a CAGEAN approach (Quinn and Deriso 1999).

To evaluate these two options, we ran profile likelihoods over q for the four model combinations:

	Prior on q	Stock-recruitment curve
Model 1	Diffuse	Included
Model 1b	More informative	Included
Model 2	Diffuse	Excluded
Model 2b	More informative	Excluded

The results of these profiles together with the Model 1 analogs are shown in Fig. 10. Adding the more informative prior distribution to either Model 1 or 2 resulted in higher values for q (implying lower stock sizes). Importantly, even with the effect of fitting the stock-recruitment curve completely omitted from the model (Models 2 & 2b) the estimates of q were between 0.2 and 0.25. From this result, we conclude that the inclusion of the stock-recruitment has little effect on the estimation of survey catchability.

In all, 9 models were evaluated and compared (Table 10). Most are variants of the stochastic age-structured production model (Model 1 and Models 1b-1e). Model 2 (and Models 2b and 2c) are CAGEAN-like in that no underlying productivity function was estimated. Model 3 was a simple *non*-stochastic age-structured production model.

We provide summary results for these models in Table 11. This table has three parts: the top section deals with stock status, the middle concerns the effect of different models on projection values, and the lower part provides indications of fit for the different data components.

As noted above, we developed a model variant using the Ricker curve instead of the Beverton-Holt form for the stock-recruitment relationship. We refer to this as Model 1e. This model fit the data slightly less well than Model 1c (-ln(Likelihood) was 155.23 compared to 154.97 for

Model 1c). The estimated unfished spawning biomass was also very similar between these two. The shapes of the estimated curves are slightly different with the initial slope for the Ricker somewhat smaller than that of the Beverton-Holt form (Fig. 11). The largest difference in the productivity estimates was in the $MSYL$ (the fraction of unfished spawning biomass where MSY occurs). For Model 1e $MSYL = 0.438$, while for Model 1c $MSYL = 0.343$. The use of the Ricker stock-recruitment relationship suggests that the stock should be held at a higher fraction of unfished spawning biomass.

Ignoring the CPUE data (Model 2c) has negligible effect on the survey catchability estimates and degrades the fit only slightly to the CPUE data itself. This suggests that there is some consistency with the observed trend and the estimated biomass changes.

Since Model 1c captures some of the range of the other model specifications, we selected it as our main reference case from which to base remaining inferences. Model 1c is only marginally different than Model 1. However, when integrating out over all parameter uncertainty, the behavior and non-linear effect at high levels of steepness (suggesting considerably high productivity levels at low recommended stock sizes) dominates the critical result regarding current stock size relative to the target, B_{msy} stock size. Estimates of the numbers at age for Model 1c are presented in Table 12.

1.4.2. Reference model results

Time series of biomass, recruitment and fishing mortality or exploitation rate estimates are shown in Fig. 12. The fit to the stock-recruitment relationship indicates a fair amount of variability, especially during the early part of the time series when several strong year-class occurred. Above-median recruitment levels were generated throughout the period 1956-1966 with relatively poor year-class strengths since the 1970 year-class. The residuals to the CPUE data indicate a pattern of low, followed by higher-than expected observations. The residuals for the survey data appear more regularly dispersed over time. Fishing mortality peaked during the mid 1960s and have stabilized between 0.05 and 0.10. The selectivity patterns estimated for the fishery are presented in Fig. 13. There is a moderate change in selectivity pattern over time. The fit of the model to the size and age composition data for both the fishery and surveys are presented in Figures 14 to 17.

Stock status

The critical value for stock status is represented by the estimates of current (2000) stock size relative to the target (B_{msy}) level. For obvious reasons, the expression of this quantity's marginal probability distribution is important. We assess this three ways: using the delta-method approximation (requiring joint multivariate normal distributions to be satisfied); using profile-likelihood methods (assuming that the ridge approximates the multivariate volume, i.e., parameter curvature in likelihood space is minimal); and using multivariate integration methods (MCMC). The first two methods are only approximations to the marginal distribution, while the latter can be shown to converge to the true posterior distribution, provided the number of simulations has adequately explored the likelihood surface. We ran the MCMC with length 5 million and sampled every 1,000th parameter vector from the original chain. We compared this with different chains of length 1 million for convergence (but with different random number starting seeds) and found them to be very similar (suggesting convergence). The normal approximation and the profile likelihood results are very similar while the marginal distribution from the MCMC results is significantly shifted to the right (Fig. 18). This means that when all parameter uncertainty is accounted for, the current status relative to the target stock size is considerably improved. Understanding this result requires some intuition about these types of age-structured models and the functional form for the stock-recruitment relationship. In sequential age-structured models, it is common to have non-zero probability that the stock size is several times larger than the current maximum likelihood estimate (or highest posterior density). On the other side (small stock sizes), probability quickly approaches zero as the stock size approaches the actual catch (since catch cannot logically exceed biomass). Also, the stock-recruitment steepness (h) inversely affects estimates of B_{msy}. That is, at high levels of steepness, the value of B_{msy} decreases. The marginal posterior distribution of steepness is shifted slightly from the prior with more probability towards the high side (Fig. 19). Lower values of steepness are somewhat less likely than higher values. These factors shed some light as to why the approximations (profile likelihood and delta-method) are poor at accounting for all sources of uncertainty.

We conclude that more accurate probability statements about the current stock level relative to the target (B_{msy}), as presented here, are most appropriate for assessing the stock condition. There is a relatively low probability that the 2001 spawning stock level is below one half of B_{msy} (~15% chance), even as applied to the more conservative models (with higher values of survey catchability).

Comparison with previous assessment

This year's model gave results substantially higher than that of the 1998 assessment (Fig. 20). These are due to the differences in the estimates of survey catchability that has come about (discussed above), and due to the increased abundance estimate from the 1998 survey.

1.4.3. Harvest projections

Reference harvest levels

To evaluate the properties of the yield computations we plotted the yield curve relative to values obtained under different spawning biomass-per-recruit (SPR) harvest rates (e.g., $F_{50\%}$). This suggests that for westcoast POP, the F_{msy} value is closest to the $F_{50\%}$ level (Fig. 22). The uncertainty of these values are represented in Fig 23. This figure reflects the greater uncertainty in F_{msy} compared to the SPR values since there is a large degree of uncertainty in the stock productivity estimates (via the internally fitted stock-recruitment relationship). The uncertainty in the SPR values only arises from uncertainty in fishery selectivity and natural mortality estimates.

Harvest rates, and associated yields over the next 3 years are presented in the middle part of Table 11. These show some effect of different harvest levels and future stock sizes but only represent the "point estimates" of these outcomes. In our analyses, we performed a Markov-chain Monte Carlo integration scheme to better encapsulate the uncertainty in the multivariate parameter space.

Rebuilding considerations

We analyzed the stock under Model 1c by projecting forward for 11 years (to 2011) showing alternative current stock sizes and outcomes under different harvest policies. The harvest policies were implemented as fixed fishing mortality rates and outcomes are based on future uncertain recruitment and current parameter uncertainty (e.g., in selectivity, natural mortality, and current stock size). Results show that under most policies, the expected value for target biomass (B_{msy}) will be attained by the year 2011 (Figs. 25 and 26). The expected value of the ratio of female spawning biomass in 2011 over B_{msy} is close to 1. However, the large degree of uncertainty in current stock size increases in future projections. Conclusions about rebuilding potential must always acknowledge this level of uncertainty. Given the available data, and integrating over the model uncertainty suggests a relatively high probability that the stock is above the target (B_{msy}) stock size.

1.5. Recommendations

In this assessment we investigated several alternative model specifications for the different data types. Our findings suggest that the current stock level has apparently begun to recover, based on new (but limited) recruitment information from the 1990s. A great deal of uncertainty remains on the stock status relative to a "target" stock size. Analyses of otoliths for age-determinations from the 1995 survey, and from past and future fishery harvests should be re-established as a priority. Also, analyses of stock-recruitment data should account for implied assumptions about unfished stock size. That is, unfished stock size should be consistent with estimated levels prior to fishery developments.

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1.8. Tables

Table 1. Pacific Fishery Management Council groundfish management/regulatory actions regarding Pacific ocean perch (POP) since Fishery Management Plan implementation in 1982.

Date	Regulatory Action
November 10, 1983	Recommended closure of Columbia area to POP fishing until the end of the year as 950 t OY for this species has been reached; retain 5,000 pound trip limit or 10 percent of total trip weight on landings of POP in the Vancouver area.
January 1, 1984	Continuation of 5,000 pound trip limit or 10 percent of total trip weight on POP as specified in FMP. Fishery closes when area OY's are reached (see action effective November 10, 1983 above).
August 1, 1984	Recommended immediate reduction in trip limit for POP in the Vancouver and Columbia areas to 20 percent by weight of all fish on board, not to exceed 5,000 pounds per vessel per trip. When OY is reached in either area, landings of POP will be prohibited in that area (Oregon and Washington implemented POP recommendation in mid-July).
August 16, 1984 (Automatic closure)	Commercial fishing for POP in the Columbia area closed for remainder of the year. (See items regarding this species effective January 1 and August 1, 1984 above.)
January 10, 1985	Recommended Vancouver and Columbia areas POP trip limit of 20 percent by weight of all fish on board (no 5,000 pound limit as specified in last half of 1984).
April 28, 1985	Recommended the Vancouver and Columbia areas POP trip limit be reduced to 5,000 pounds or 20 percent by weight of all fish on board, whichever is less. Landings of POP less than 1,000 pounds will be unrestricted. The fishery for this species will close when the OY in each area is reached.
June 10, 1985	Recommended landings of POP up to 1,000 pounds per trip will be unrestricted regardless of the percentage of these fish on board.
January 1, 1986	Recommended the POP limit in the area north of Cape Blanco (42 degrees, 50 minutes N) should be 20 percent (by weight) of all fish on board or 10,000 pounds whichever is less; landings of POP should be unrestricted if less than 1,000 pounds regardless of percentage on board; Vancouver area OY = 600 t; Columbia area OY = 950 t.
December 1, 1986	OY quota for POP reached in the Vancouver area; fishery closed until January 1, 1987.
January 1, 1987	Recommended the coastwide POP limit should be 20 percent of all legal fish on board or 5,000 pounds whichever is less (in round weight); landings of POP unrestricted if less than 1,000 pounds regardless of percentage on board; Vancouver area OY = 500 t; Columbia area OY = 800 t.
January 1, 1988	Recommended the coastwide POP trip limit should be 20 percent (by weight) of all fish on board or 5,000 pounds, whichever is less; landings of POP be unrestricted if less than 1,000 pounds regardless of percentage on board; Vancouver area OY = 500 t; Columbia area OY = 800 t.
January 1, 1989	Established the coastwide POP trip limit at 20 percent (by weight) of all fish on board or 5,000 pounds whichever is less; landings of POP unrestricted if less than 1,000 pounds regardless of percentage on board (Vancouver area OY = 500 t; Columbia area OY = 800 t).
July 26, 1989	Reduced the coastwide trip limit for POP to 2,000 pounds or 20 percent of all fish on board, whichever is less, with no trip frequency restriction. Increased the Columbia area POP OY from 800 to 1,040 t.
December 13, 1989	Closed the POP fishery in the Columbia area because 1,040 t OY reached.
January 1, 1990	Established the coastwide POP trip limit at 20 percent (by weight) of all fish on board or 3,000 pounds whichever is less; landings of POP be unrestricted if less than 1,000 pounds regardless of percentage on board. (Vancouver area OY = 500 t; Columbia area OY = 1,040 t).
January 1, 1991	Established the coastwide POP trip limit at 20 percent (by weight) of all fish on board or 3,000 pounds whichever is less; landings of POP be unrestricted if less than 1,000 pounds regardless of percentage on board (harvest guideline for combined Vancouver and Columbia areas = 1,000 t).
January 1, 1992	Established the coastwide POP trip limit at 20 percent (by weight) of all groundfish on board or 3,000 pounds whichever is less; landings of POP be unrestricted if less than 1,000 pounds regardless of percentage on board (harvest guideline for combined Vancouver and Columbia areas = 1,550 mt).
January 1, 1993	Continued the coastwide POP trip limit at 20 percent (by weight) of all groundfish on board or 3,000 pounds whichever is less; landings of POP be unrestricted if less than 1,000 pounds regardless of percentage on board (harvest guideline for combined Vancouver and Columbia areas = 1,550 mt).
January 1, 1994	Adopted the following management measure for the limited entry fishery in 1994: POP: Trip limit of 3,000 pounds or 20 percent of all fish on board, whichever is less, in landings of POP above 1,000 pounds. Adopted the following management measure for open access gear except trawls in 1994: Rockfish: Limit of 10,000 pounds per vessel per trip, not to exceed 40,000 pounds cumulative per month, and the limits for any rockfish species or complex in the limited entry longline or pot fishery must not be exceeded.
May 1, 1994	Changed trip limit for rockfish taken with setnet gear off California. The 10,000 pound trip limit for rockfish caught with setnets, which applied to each trip, was removed. The 40,000 pound cumulative limit that applies per calendar month remains in effect.
January 1, 1995	Established cumulative trip limits of 6,000 pounds per month.
January 1, 1996	Established cumulative trip limits of 10,000 pounds every two months.
July 1, 1996	Reduced cumulative 2-month trip limit to 8,000 pounds.
January 1, 1997	Established cumulative trip limits of 10,000 pounds every two months.
January 1998	Harvest guidelines reduced from 750 mt to 650 mt with ABC=0. Limited entry fishery under 8,000 pounds per two-months until September with monthly limits of 4,000 pounds
January 1999	Monthly cumulative trip limit of 4,000 pounds for limited entry fishery. A 100 pound per month limit established for open access fishery.

Table 2. Pacific ocean perch catches in the and by fleet (primarily within the US Vancouver and Columbia areas).

Year	Foreign (all areas)	Total domestic (all areas)	Total (all areas & fleets)
1956	-	2,119	2,119
1957	-	2,320	2,320
1958	-	1,508	1,508
1959	-	1,860	1,860
1960	-	2,246	2,246
1961	-	3,924	3,924
1962	-	5,503	5,503
1963	-	6,449	6,449
1964	-	5,517	5,517
1965	375	7,660	8,035
1966	20,500	3,039	23,539
1967	33,204	885	34,089
1968	18,783	592	19,375
1969	4,361	692	5,053
1970	4,435	1,649	6,084
1971	4,792	997	5,789
1972	3,995	578	4,573
1973	3,148	353	3,501
1974	1,060	326	1,386
1975	1,201	623	1,824
1976	1,146	1,366	2,512
1977	7	1,180	1,187
1978	0	2,014	2,014
1979	0	1,854	1,854
1980	0	1,867	1,867
1981	0	1,359	1,359
1982	0	980	980
1983	0	1,797	1,797
1984	0	1,585	1,585
1985	0	1,329	1,329
1986	0	1,273	1,273
1987	0	1,075	1,075
1988	0	1,152	1,152
1989	0	1,405	1,405
1990	0	968	968
1991	0	1,224	1,224
1992	0	908	908
1993	0	1,093	1,093
1994	0	858	858

1995	0	701	701
1996	0	645	645
1997	0	515	515
1998		472	472
1999		544	544
2000		270	270

Table 3. Domestic fishery catch at age for Vancouver and Columbia areas combined (from Gunderson, 1981). Otolith surface ageing method was used for these years. Note that the ages 15 and older were omitted to avoid potential problems with these biased ageing methods.

Age	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
3	0	0	0	0	6	0	0	2	0	0	0	0	0	0	0
4	0	0	19	0	0	0	4	9	0	0	0	4	2	0	0
5	12	44	29	18	22	0	31	29	6	87	200	7	23	8	4
6	24	61	559	7	233	12	65	44	14	88	1,353	91	48	17	23
7	82	543	1,206	64	319	117	142	70	15	105	425	529	95	34	53
8	294	872	1,648	109	711	291	277	110	28	67	289	144	333	87	159
9	353	1,580	1,191	97	1,459	956	540	311	94	101	201	118	183	257	345
10	801	2,780	1,667	230	1,081	1,640	990	709	241	218	316	98	195	191	351
11	1,401	4,989	2,484	578	907	1,083	1,511	1,170	402	321	420	155	208	166	214
12	2,731	8,115	4,142	1,267	904	798	620	1,326	505	373	403	157	279	195	189
13	1,648	6,322	3,845	1,369	937	686	402	564	370	390	297	141	264	178	197
14	1,201	5,496	3,130	1,103	807	652	420	279	142	351	248	122	296	170	200
15	1,425	4,523	2,703	1,060	818	667	426	242	106	97	133	83	215	164	176
16	1,342	3,595	2,051	586	700	572	402	218	79	77	62	71	170	146	166
17	812	2,501	1,317	215	390	538	377	233	66	86	61	42	106	124	146
18	589	1,326	938	184	269	252	271	187	65	70	60	37	68	99	107
19	259	992	651	71	148	220	137	146	41	54	45	36	33	73	60
20	118	379	520	7	74	149	90	105	37	32	49	27	30	44	69
21	35	115	248	0	27	75	58	72	34	23	15	12	17	32	39
22	12	141	146	4	0	21	31	25	25	12	25	2	11	21	23
23	12	44	34	0	0	0	6	10	14	8	15	5	3	18	16
24	0	27	0	0	0	0	0	0	5	3	16	1	0	2	20
25	0	0	0	0	0	0	0	0	0	0	0	0	0	4	12

Table 4. Survey age compositions for the combined Vancouver and Columbia areas. Note that the age 1 and 2 values for the population were not used in the model, neither were the data from 1977-1980 since the sample size was quite low and they were aged using surface methods.

Age	**1977**	**1979**	**1980**	**1985**	**1989**	**1992**	**1998**
1	0	0	0	0	46,138		
2	18,214	2,556	0	21,200	254,816		38,718
3	84,582	13,231	0	122,477	89,226	798,759	2,056,539
4	119,793	228,325	295,155	332,342	3,176,682	3,368,042	3,457,344
5	125,448	667,058	702,456	731,141	1,219,343	2,750,737	363,980
6	460,779	652,383	591,543	1,017,246	656,796	1,076,992	501,087
7	2,631,845	870,267	350,490	418,657	833,499	1,255,653	1,114,104
8	745,320	2,341,122	514,736	290,206	2,353,474	1,020,789	1,164,323
9	474,994	3,722,415	576,100	294,572	928,618	627,615	617,259
10	383,316	1,663,880	268,615	603,853	748,928	540,627	474,097
11	455,394	1,148,334	253,944	523,611	573,984	2,472,883	496,022
12	900,039	1,169,177	371,575	301,193	416,323	1,229,444	331,823
13	888,055	1,004,988	403,092	405,146	353,090	668,764	588,042
14	1,251,141	1,080,766	224,522	553,271	219,216	306,908	384,535
15	1,013,324	933,723	365,190	554,201	24,770	390,237	583,973
16	1,036,159	914,997	240,000	290,312	129,282	541,074	442,703

17	551,481	738,255	192,922	210,758	20,177	47,713	442,686
18	939,938	592,137	220,671	284,327	9,974	130,796	339,970
19	976,370	418,312	0	189,918	36,992	82,358	407,549
20	768,559	320,882	0	265,433	20,936	213,467	49,590
21	406,035	171,105	64,715	263,709	49,188	148,865	223,090
22	139,400	108,387	0	213,783	23,570	105,234	94,158
23	98,700	58,304	0	217,418	119,073	77,359	205,193
24	7,982	17,428	0	200,765	132,707	142,147	39,458
25	54,337	15,899	0	3,163,096	2,195,421	1,725,477	3,439,282

Table 5. Biomass index from triennial groundfish surveys by area, 1977 - 1998.

Area/ Year	Depth (m)	Biomass Estimates	Sampling CV
US Vancouver			
1977	91-366	7,589	64.8%
1980	55-366	3,128	53.7%
1983	55-366	3,786	37.6%
1986	55-366	1,214	38.3%
1989	55-366	7,719	55.3%
1992	55-366	5,358	65.4%
1995	55-500	3,555	63.0%
1998	55-500	4,495	45.0%
Columbia			
1977	91-366	6,656	22.5%
1980	55-366	3,340	81.4%
1983	55-366	2,947	43.4%
1986	55-366	1,583	69.8%
1989	55-366	1,536	53.9%
1992	55-366	2,243	45.7%
1995	55-500	761	28.0%
1998	55-500	3,084	43.0%

Table 6. Survey estimates from directed Pacific ocean perch surveys for US Vancouver and Columbia areas combined, 1979 and 1985.

Year	Biomass	Cv
1979	14,245	29.6%
1985	10,696	20.1%

Table 7. List of data and time periods covered for the current assessment.

Data source	Years

Fishery Biased Age Composition	1966-1980
Fishery Size Composition	1968-89, 1994-1999
Fishery CPUE	1956-73
Triennial Survey Biomass	1977, 1980, 1983, 1986, 1989, 1992, 1995, 1998
Triennial Survey Age Composition.	1989, 1992, 1998
Triennial Survey Size Composition.	1977, 1980, 1983, 1995
Rockfish Survey Biomass	1979, 1985
Rockfish Survey Age Composition	1985
Rockfish Survey Size Composition	1979

Table 8. Equations describing catch-at-age model used for this assessment.

General Definitions	Symbol/Value	Use in Catch at Age Model
Year index: $i = \{1956, \ldots, 2000\}$	1956 … 2000 = 45 years	
Age index: $j = \{3, 4, 5, \ldots, 24, 25^+\}$	3 … 25^+ = 23 age groups	
Mean weight by age j	W_j	
Maximum age beyond which selectivity is constant	*Maxage*	Selectivity parameterization
Instantaneous Natural Mortality	M	Prior distribution = lognormal(0.05, 0.1^2)
Size-age error, $j = 3, \ldots, 25^+$: the probability of size of true age j fish as in length bin j', i.e.,	$A_{jj'}$ $\sum_{j'=1}^{25} A_{jj'} = 1.0$	$\hat{P}_{ij'} = E\left[P_{ij'}\right] = \sum_{j=1}^{25} P_{ij} A_{jj'}$
Sample size for proportion at sex k and age j in year i	T_i	Scales multinomial assumption about estimates of proportion at age
Survey catchability coefficients	Q^s, Q^R	Prior distribution = lognormal(1.0 , 0.2^2)

Data Description	**Symbol/Constraints**	**Expected Values Based on Catch At Age Model**
Survey abundance index by year i = 1977, 80, 83, 86, 89, 92, 95, & 1998	Y_i^s	$\hat{Y}_i^s = Q_i^s \sum_{j=3}^{25^+} s_j^s W_{ij} N_{ij}$
Rockfish survey index by year i = 1979 and 1985	Y_i^R	$\hat{Y}_i^R = Q_i^R \sum_{j=3}^{25^+} s_j^s W_{ij} N_{ij}$
Historical CPUE index by year i = 1956, 1957, …, 1973	Y_i^f	$\hat{Y}_i^f = Q_i^f \sum_{j=3}^{25^+} s_j^f W_{ij} N_{ij} \; c$
Catch biomass by Year, i = 1956,…,2000	C_i	$\hat{C}_i = \sum_j W_{ij} N_{ij} \frac{F_{ij}}{Z_{ij}} \left(1 - e^{-Z_{ij}}\right)$
Proportion at age or length bin j, in year I	P_{ij}, $\sum_{j=1}^{25} P_{ij} = 1.0$	$P_{ij} = \frac{N_{ij} s_{ij}^f}{\sum_{l=1}^{25} N_{il} s_{il}^f}$
Initial numbers at age	$j = 3$	$N_{k,1956,3} = e^{\mu_R + \rho_{1956}}$
	$3 < j < 25$	$N_{1956,j} = e^{\mu_R + \rho_{1958-j}} \prod_{l=3}^{j} e^{-M}$
	$j = 25^+$	$N_{1956,25} = N_{1956,24} \left(1 - e^{-M}\right)^{-1}$
Subsequent years…	$j = 3$	$N_{i,3} = \frac{S_{i-3} e^{\rho_i}}{\alpha + \beta S_{i-3}}$
(i >1956)	$3 < j < 25$	$N_{i,j} = N_{i-1,j-1} e^{-Z_{i-1,j-1}}$
	$j = 25^+$	$N_{i,25^+} = N_{i-1,24} \, e^{-Z_{i-1,24}} + N_{i-1,25} \, e^{-Z_{i-1,25}}$

Table 8. (continued)

Parameter Description	**Estimated Parameter, Constraints**	**Derived Parameters, Use in Catch at Age Model**	
Index catchability	μ^s, μ^f, μ^R	$Q_i^s = e^{\mu^s}$, $Q_i^R = e^{\mu^R}$, $Q_i^f = e^{\mu^f}$	
Mean effect	η_j^s, $\sum_{j=3}^{25^+} \eta_j^s = 0$	$s_j^s = e^{\eta_j^s}$	
Age effect			
Instantaneous fishing mortality		$F_{ij} = e^{\mu_f + \eta_j^f + \phi_i}$	
mean fishing effect	μ_f		
annual effect of fishing in year i	ϕ_i, $\sum_{i=1956}^{2000} \phi_i = 0$		
age effect of fishing (regularized form)	η_j^f, $\sum_{j=3}^{25^+} \eta_j = 0$	$s_j^f = e^{\eta_j^f}$,	$j \leq$ maxage
		$s_j^f = e^{\eta^f_{\text{maxage}}}$	$j >$ maxage
Natural Mortality	M		
Total mortality		$Z_{ij} = F_{ij} + M$	
Recruitment	μ_R		
Beverton-Holt form			
Year effect, $i = 1956, \ldots, 98$	ρ_i, $\sum_{i=1935}^{2000} \rho_i = 0$	$R_i = e^{\mu_R + \rho_i}$	

Table 8. (continued)

Likelihood Component	Specification	Description / notes
Abundance indices	$L_1 = \lambda_1^s \sum_i \left(Y_i^s - \hat{Y}_i^s \right)^2$	Triennial Survey
	$L_2 = \lambda_1^f \sum_i \ln\left(Y_i^f / \hat{Y}_i^f \right)^2$	CPUE index
	$L_3 = \lambda_1^R \sum_i \left(Y_i^R - \hat{Y}_i^R \right)^2$	Rockfish Survey index
Smoother for selectivities	$L_4 = \sum_l \Big[\lambda_2^l \sum_{j=3}^{25^+} \left(\eta_{j+2}^l + \eta_j^l - 2\eta_{j+1}^l \right)^2 +$ $\lambda_3^l \sum_{j=3}^{25^+} \mathrm{I}\left(\eta_j^l < \eta_{j-1}^l \right) \left(e^{\eta_j^l} - e^{\eta_{j-1}^l} \right)^2 +$ $\lambda_4^l \sum_{i=1}^{T} \sum_{j=3}^{25^+} \left(\eta_{1957+i\cdot m,j}^l \right)^2 \Big]$	Smoothness (second differencing), Degree of declining selectivity with age, and Regularity $T = \mathrm{int}\left[\frac{2000-1958}{m} \right]$, m = the number of consecutive years where selectivity remains constant over time. Note: *l={s, R, or f}* for survey and fishery selectivity
Recruitment regularity	$L_5 = \lambda_5 \sum_{i=1956}^{2000} \rho_i^2$	Influences estimates where data are lacking (e.g., if no signal of recruitment strength is available, then the recruitment estimate will converge to median value).
Catch biomass likelihood	$L_6 = \lambda_6 \sum_{i=1956}^{2000} \ln\left(C_i / \hat{C}_i \right)^2$	
Proportion at age likelihood	$L_7 = -\sum_{l,i,j} T_{ij}^l P_{ij}^l \log\left(\hat{P}_{ij}^l \cdot P_{ij}^l \right)$	*l={s, f}* for survey and fishery age composition observations
Fishing mortality regularity	$L_8 = \lambda_7 \sum_{i=1956}^{2000} \phi_i^2$	(relaxed in final phases of estimation)
Overall objective function to be minimized	$\dot{L} = \sum_{i=1}^{8} L_i$	

Table 9. List of lambda's, their influence on model fitting, and standard deviations.

Lambda	Description	Log-scale standard deviation (unless otherwise noted)
λ_1^s	Variance term for triennial survey	(annual, sampling error)
λ_1^R	Variance term for rockfish index	(annual, sampling error)
λ_1^f	Variance term for historical CPUE data	0.20
λ_2^f	Variance term for fishery selectivity stability	0.16
λ_2^s	Variance term for survey selectivity stability	0.71
λ_3^f	Variance term for degree of declining fishery selectivity	0.07
λ_3^s	Variance term for degree of declining survey selectivity	0.07
λ_4^f	Variance selectivity regularity	0.07
λ_5	Variance term for recruitment regularity	2.24
λ_6	Variance term for matching catch biomass	0.07
λ_7	Variance term for annual fluctuations in fishing mortality	2.24

Table 10. Description of alternative models evaluated for sensitivity analyses.

Model	**Description**
1	Reference case, stochastic age-structured production model
2	Stochastic age-structured model (CAGEAN-like, no underlying productivity function)
3	Deterministic age-structured production model
1b, 2b	Same as Models 1 and 2, but with less informative prior on survey catchability
1c	Same as Model 1 but with Dorn's (2000) prior on h, stock-recruitment steepness
1d	Same as Model 1b but with Dorn's (2000) prior on h, stock-recruitment steepness
1e	Same as Model 1c but with Ricker form of stock-recruitment curve
2c	Same as Model 2 but ignore CPUE data

Table 11. Summary of stock condition (in biomass), projections, and relative fits among different models based on point estimates (the "mode" of the posterior distribution). Note: coefficients of variation (CV's) are in parentheses.

	Model 1	Model 1b	Model 1c	Model 1d	Model 1e	Model 2	Model 2b	Model 2c	Model 3
2001 Spawning Biomass	10,019	14,838	10,244	14,911	10,295	9,158	12,615	11,763	90,887
	(42%)	(45%)	(41%)	(43%)	(42%)	(42%)	(45%)	(49%)	(15%)
Unfished Spawning Biomass	57,028	60,284	56,653	60,212	56,905	44,260	45,801	39,953	125,960
	(18%)	(19%)	(18%)	(19%)	(17%)	(28%)	(29%)	(37%)	(13%)
B_{msy}	20,066	19,987	19,407	19,828	24,943	9,424	9,746	8,508	15,603
2001 / unfished spawning biomass	0.18	0.25	0.18	0.25	0.18	0.21	0.28	0.29	0.72
2000 Sp.Biom / Bmsy	0.478	0.710	0.505	0.719	0.395				5.767
	(55%)	(60%)	(50%)	(51%)	(44%)				(129%)
MSY	1,588	1,916	1,665	1,936	1,956				7,158
	(43%)	(45%)	(35%)	(36%)	(42%)				(27%)
MSYL	0.352	0.332	0.343	0.329	0.438				0.124
	(20%)	(26%)	(17%)	(20%)	(5%)				(128%)
F 1999 / F_{msy}	0.342	0.191	0.309	0.187	0.336				0.010
	(89%)	(98%)	(76%)	(79%)	(72%)				(111%)
Natural Mortality	0.050	0.051	0.050	0.051	0.050	0.049	0.049	0.049	0.053
	(9%)	(9%)	(9%)	(9%)	(9%)	(10%)	(10%)	(10%)	(8%)
Stock-recruitment steepness	0.52	0.57	0.54	0.58	0.46				1.00
	(38%)	(43%)	(31%)	(32%)	(22%)				(11%)
ρ (autocorrelation)	0.56	0.55	0.56	0.55	0.57				0.90
	(20%)	(21%)	(20%)	(21%)	(20%)				(1%)
Triennial Survey q	0.241	0.178	0.239	0.178	0.238	0.261	0.207	0.216	0.036
	(25%)	(32%)	(25%)	(31%)	(25%)	(23%)	(29%)	(31%)	(19%)
Rockfish Survey q	0.458	0.372	0.455	0.371	0.454	0.497	0.429	0.446	0.067
	(25%)	(30%)	(25%)	(30%)	(26%)	(24%)	(27%)	(29%)	(24%)
SPR F=0	7.78	7.61	7.82	7.62	7.85	8.22	8.09	8.20	7.19
Projections	**Model 1**	**Model 1b**	**Model 1c**	**Model 1d**	**Model 1e**	**Model 2**	**Model 2b**	**Model 2c**	**Model 3**
2011 Stock size @ F = 0	17,500	25,411	18,185	25,603	17,933	19,656	24,697	22,744	101,830
2011 Stock size @ Fmsy	12,952	17,666	13,160	17,691	13,295	9,277	11,163	10,234	28,750
2011 Stock size @ F40%	11,402	16,453	11,894	16,587	11,692	13,375	16,455	15,129	66,577
2011 Stock size @ F50%	12,967	18,740	13,512	18,890	13,296	15,028	18,610	17,124	74,932
2001 Harvest @ Fmsy	834	1,489	923	1,523	849	2,137	2,971	2,750	26,417
2002 Harvest @ Fmsy	880	1,557	972	1,592	896	2,162	2,997	2,778	22,882
2003 Harvest @ Fmsy	921	1,616	1,017	1,651	938	2,175	2,997	2,782	19,990
2001 Harvest @ F50%	831	1,247	848	1,252	849	751	1,044	966	6,512
2002 Harvest @ F50%	877	1,313	895	1,319	895	809	1,122	1,039	6,341
2003 Harvest @ F50%	918	1,372	939	1,379	938	864	1,193	1,106	6,184
Fit to data (R.M.S.E.)									
Triennial Survey	0.415	0.430	0.414	0.430	0.414	0.416	0.427	0.427	0.481
Rockfish Survey	0.063	0.098	0.065	0.099	0.067	0.050	0.077	0.071	0.282
CPUE	0.173	0.169	0.172	0.169	0.172	0.170	0.168	0.192	0.238
Catch	0.004	0.003	0.004	0.003	0.004	0.004	0.003	0.001	0.004
Effective Sample Size									
Survey Age	54	54	54	54	54	55	55	56	31
Fishery Age	185	183	185	183	185	188	187	184	40
Survey Size	31	32	31	32	32	30	31	30	36
Fishery Size	158	160	158	160	158	156	158	156	128
Likelihoods	**Model 1**	**Model 1b**	**Model 1c**	**Model 1d**	**Model 1e**	**Model 2**	**Model 2b**	**Model 2c**	**Model 3**
Total	153.51	151.02	154.97	152.46	155.23	149.37	147.69	140.82	282.29
Catch	0.07	0.04	0.07	0.04	0.06	0.06	0.04	0.01	0.07
Triennial Survey	4.47	4.10	4.44	4.10	4.45	4.34	3.96	3.97	6.58
Rockfish Survey	0.05	0.11	0.05	0.11	0.06	0.03	0.07	0.06	0.70
CPUE	-22.27	-22.51	-22.28	-22.51	-22.29	-22.44	-22.61	-28.97	-16.25
Survey Age	25.71	25.67	25.73	25.67	25.76	24.16	24.10	24.02	45.05
Fishery Age	42.67	42.69	42.67	42.69	42.64	41.78	41.82	41.27	98.91
Survey Size	25.34	25.28	25.37	25.28	25.38	25.20	25.14	25.10	35.81
Fishery Size	57.65	57.74	57.66	57.74	57.74	57.59	57.59	57.97	71.88
Selectivity Components	17.39	17.61	17.35	17.60	17.27	16.16	16.29	16.20	36.09
Recruitment curve	-4.31	-4.74	-4.28	-4.74	-4.21				-17.67
Recruitment variability	3.84	3.36	3.81	3.36	3.85				0.00
Prior on M	-1.38	-1.35	-1.38	-1.35	-1.38	-1.34	-1.37	-1.34	-1.16
Prior on Steepness (h)	0.00	0.00	1.45	1.44	1.56				
Prior on survey catchability (q)	4.28	3.02	4.32	3.02	4.34	3.83	2.64	2.53	22.29

Table 12. Numbers at age (millions of fish) for the US west coast population of Pacific ocean perch, 1956-2000; Model 1c.

	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1956	26.0	10.2	6.2	4.8	4.1	3.8	3.6	3.5	3.5	3.4	3.3	3.2	3.1	3.0	2.8	2.7	2.6	2.5	2.4	2.4	2.4	2.6	48.2
1957	38.3	24.7	9.7	5.9	4.5	3.9	3.5	3.4	3.3	3.2	3.2	3.1	3.0	2.9	2.8	2.6	2.5	2.4	2.3	2.2	2.2	2.2	47.4
1958	30.9	36.4	23.5	9.2	5.6	4.3	3.6	3.3	3.1	3.0	3.0	2.9	2.8	2.7	2.7	2.5	2.4	2.3	2.2	2.1	2.1	2.0	46.1
1959	26.5	29.4	34.6	22.3	8.7	5.3	4.0	3.4	3.1	2.9	2.8	2.8	2.7	2.6	2.6	2.5	2.4	2.3	2.2	2.1	2.0	1.9	45.1
1960	16.3	25.2	28.0	32.9	21.2	8.2	5.0	3.8	3.2	2.9	2.7	2.6	2.6	2.5	2.5	2.4	2.3	2.2	2.1	2.0	2.0	1.9	43.9
1961	10.4	15.5	23.9	26.6	31.2	20.0	7.8	4.7	3.5	3.0	2.7	2.5	2.4	2.4	2.3	2.3	2.2	2.1	2.1	2.0	1.9	1.8	42.5
1962	7.7	9.9	14.8	22.7	25.1	29.4	18.7	7.2	4.3	3.2	2.7	2.4	2.3	2.2	2.1	2.1	2.1	2.0	2.0	1.9	1.8	1.7	40.6
1963	8.6	7.3	9.4	14.0	21.4	23.6	27.3	17.2	6.5	3.8	2.8	2.3	2.1	2.0	1.9	1.9	1.9	1.9	1.8	1.8	1.7	1.6	38.2
1964	12.7	8.1	7.0	8.9	13.2	20.1	21.8	24.9	15.4	5.7	3.3	2.4	2.0	1.9	1.8	1.7	1.7	1.7	1.7	1.6	1.6	1.5	35.8
1965	9.5	12.1	7.7	6.6	8.4	12.4	18.7	20.1	22.6	13.8	5.1	2.9	2.2	1.8	1.7	1.6	1.6	1.5	1.5	1.5	1.5	1.4	33.9
1966	5.3	9.0	11.4	7.3	6.2	7.8	11.5	17.0	17.9	19.8	11.9	4.4	2.6	1.9	1.6	1.5	1.4	1.4	1.4	1.4	1.4	1.3	31.6
1967	3.5	5.1	8.5	10.7	6.8	5.6	6.8	9.5	13.4	13.3	13.4	8.1	3.1	1.9	1.4	1.2	1.1	1.1	1.1	1.1	1.1	1.1	26.3
1968	2.6	3.3	4.8	7.9	9.7	5.8	4.5	5.0	6.4	8.0	6.6	6.8	4.5	1.9	1.2	0.9	0.8	0.8	0.7	0.7	0.7	0.8	18.8
1969	2.3	2.5	3.1	4.4	7.2	8.5	4.9	3.5	3.6	4.2	4.6	3.9	4.3	3.0	1.3	0.8	0.6	0.6	0.5	0.5	0.5	0.6	14.3
1970	2.1	2.2	2.4	3.0	4.2	6.7	7.8	4.3	3.1	3.0	3.4	3.7	3.2	3.6	2.5	1.1	0.7	0.6	0.5	0.5	0.5	0.5	13.0
1971	2.2	2.0	2.1	2.2	2.8	3.8	6.0	6.8	3.7	2.5	2.3	2.6	3.0	2.6	3.0	2.1	0.9	0.6	0.5	0.4	0.4	0.4	11.5
1972	2.7	2.1	1.8	2.0	2.1	2.5	3.4	5.1	5.5	2.9	1.9	1.9	2.1	2.4	2.2	2.5	1.8	0.8	0.5	0.4	0.4	0.3	10.2
1973	5.9	2.6	2.0	1.7	1.8	1.9	2.3	2.9	4.2	4.4	2.3	1.6	1.6	1.8	2.1	1.8	2.1	1.5	0.7	0.4	0.3	0.3	9.1
1974	2.6	5.6	2.4	1.9	1.6	1.7	1.7	2.0	2.5	3.5	3.6	1.9	1.4	1.3	1.5	1.8	1.6	1.8	1.3	0.6	0.4	0.3	8.3
1975	1.4	2.5	5.4	2.3	1.7	1.5	1.6	1.6	1.8	2.2	3.1	3.3	1.8	1.2	1.2	1.4	1.6	1.5	1.7	1.2	0.5	0.3	7.9
1976	1.1	1.4	2.3	5.1	2.2	1.6	1.4	1.4	1.4	1.6	2.0	2.8	2.9	1.6	1.1	1.1	1.3	1.5	1.3	1.5	1.1	0.5	7.5
1977	1.3	1.1	1.3	2.2	4.7	2.0	1.5	1.3	1.3	1.2	1.4	1.7	2.4	2.6	1.4	1.0	1.0	1.1	1.3	1.2	1.4	1.0	7.0
1978	1.5	1.2	1.0	1.2	2.1	4.4	1.8	1.4	1.2	1.2	1.1	1.2	1.6	2.2	2.4	1.3	0.9	0.9	1.0	1.2	1.1	1.2	7.3
1979	1.5	1.4	1.1	1.0	1.1	1.9	4.0	1.7	1.2	1.0	1.0	1.0	1.1	1.4	2.0	2.1	1.1	0.8	0.8	0.9	1.1	1.0	7.6
1980	1.5	1.4	1.4	1.1	0.9	1.1	1.7	3.7	1.5	1.1	0.9	0.9	0.9	1.0	1.2	1.7	1.9	1.0	0.7	0.7	0.8	0.9	7.6
1981	1.6	1.4	1.4	1.3	1.0	0.8	1.0	1.6	3.3	1.3	1.0	0.8	0.8	0.8	0.9	1.1	1.6	1.6	0.9	0.6	0.6	0.7	7.6
1982	2.2	1.5	1.3	1.3	1.2	0.9	0.8	0.9	1.4	3.0	1.2	0.9	0.7	0.7	0.7	0.8	1.0	1.4	1.5	0.8	0.6	0.6	7.4
1983	2.5	2.1	1.4	1.3	1.2	1.1	0.9	0.7	0.8	1.3	2.7	1.1	0.8	0.7	0.7	0.6	0.7	0.9	1.3	1.4	0.7	0.5	7.2
1984	3.5	2.3	2.0	1.3	1.2	1.1	1.0	0.8	0.6	0.7	1.2	2.4	1.0	0.7	0.6	0.6	0.6	0.6	0.8	1.1	1.2	0.6	6.7
1985	1.7	3.3	2.2	1.9	1.2	1.1	1.0	0.9	0.7	0.6	0.6	1.0	2.1	0.9	0.6	0.5	0.5	0.5	0.6	0.7	1.0	1.0	6.5
1986	1.9	1.6	3.2	2.1	1.8	1.2	1.0	0.9	0.9	0.6	0.5	0.6	0.9	1.9	0.8	0.6	0.5	0.5	0.5	0.5	0.6	0.9	6.6
1987	2.4	1.8	1.5	3.0	2.0	1.7	1.1	0.9	0.9	0.8	0.6	0.5	0.5	0.8	1.7	0.7	0.5	0.4	0.4	0.4	0.4	0.5	6.6
1988	4.0	2.3	1.7	1.4	2.8	1.8	1.5	1.0	0.8	0.8	0.7	0.5	0.4	0.5	0.8	1.6	0.6	0.5	0.4	0.4	0.4	0.4	6.4
1989	1.8	3.8	2.2	1.6	1.4	2.6	1.7	1.4	0.9	0.8	0.7	0.6	0.5	0.4	0.4	0.7	1.4	0.6	0.4	0.3	0.3	0.3	6.0
1990	3.0	1.7	3.6	2.0	1.5	1.3	2.4	1.5	1.3	0.8	0.7	0.6	0.6	0.4	0.3	0.4	0.6	1.2	0.5	0.4	0.3	0.3	5.4
1991	3.5	2.9	1.6	3.4	1.9	1.4	1.2	2.2	1.4	1.1	0.7	0.6	0.6	0.5	0.4	0.3	0.3	0.5	1.1	0.5	0.3	0.3	5.1
1992	2.4	3.3	2.7	1.5	3.2	1.8	1.3	1.0	1.9	1.2	1.0	0.6	0.5	0.5	0.4	0.3	0.3	0.3	0.5	1.0	0.4	0.3	4.7
1993	3.9	2.3	3.1	2.6	1.4	2.9	1.6	1.2	0.9	1.7	1.1	0.9	0.6	0.5	0.4	0.4	0.3	0.2	0.3	0.4	0.9	0.4	4.5
1994	3.5	3.7	2.2	3.0	2.4	1.3	2.7	1.5	1.0	0.8	1.6	1.0	0.8	0.5	0.4	0.4	0.4	0.3	0.2	0.2	0.4	0.8	4.3
1995	2.1	3.4	3.5	2.1	2.8	2.2	1.2	2.4	1.3	0.9	0.8	1.4	0.9	0.7	0.5	0.4	0.4	0.3	0.2	0.2	0.2	0.3	4.6
1996	2.6	2.0	3.2	3.3	1.9	2.6	2.1	1.1	2.2	1.2	0.8	0.7	1.3	0.8	0.7	0.4	0.4	0.3	0.3	0.2	0.2	0.2	4.5
1997	7.7	2.5	1.9	3.0	3.1	1.8	2.4	1.9	1.0	2.0	1.1	0.8	0.6	1.2	0.7	0.6	0.4	0.3	0.3	0.3	0.2	0.2	4.3
1998	5.8	7.3	2.3	1.8	2.9	2.9	1.7	2.2	1.8	0.9	1.9	1.0	0.7	0.6	1.1	0.7	0.6	0.4	0.3	0.3	0.2	0.2	4.1
1999	4.0	5.5	6.9	2.2	1.7	2.7	2.7	1.6	2.1	1.6	0.9	1.7	0.9	0.7	0.5	1.0	0.6	0.5	0.3	0.3	0.3	0.2	4.0
2000	3.3	3.8	5.3	6.6	2.1	1.6	2.5	2.5	1.4	1.9	1.5	0.8	1.6	0.9	0.6	0.5	0.9	0.6	0.5	0.3	0.3	0.2	3.9

1.9. Figures

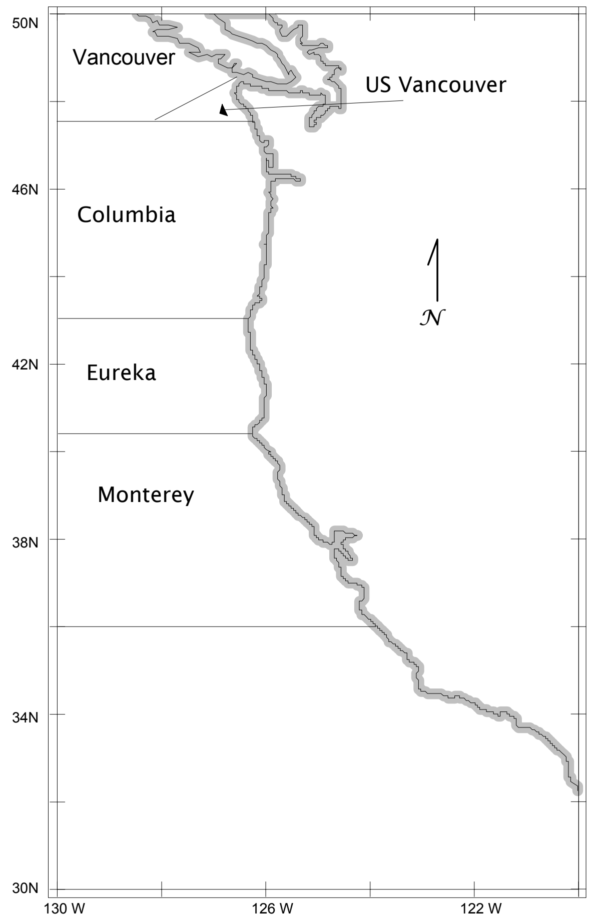


Figure 1. Map showing the INPFC areas. Currently, POP in the US Vancouver and Columbia areas are managed as a unit. Catches south of these areas are minor and are included with "other rockfish".

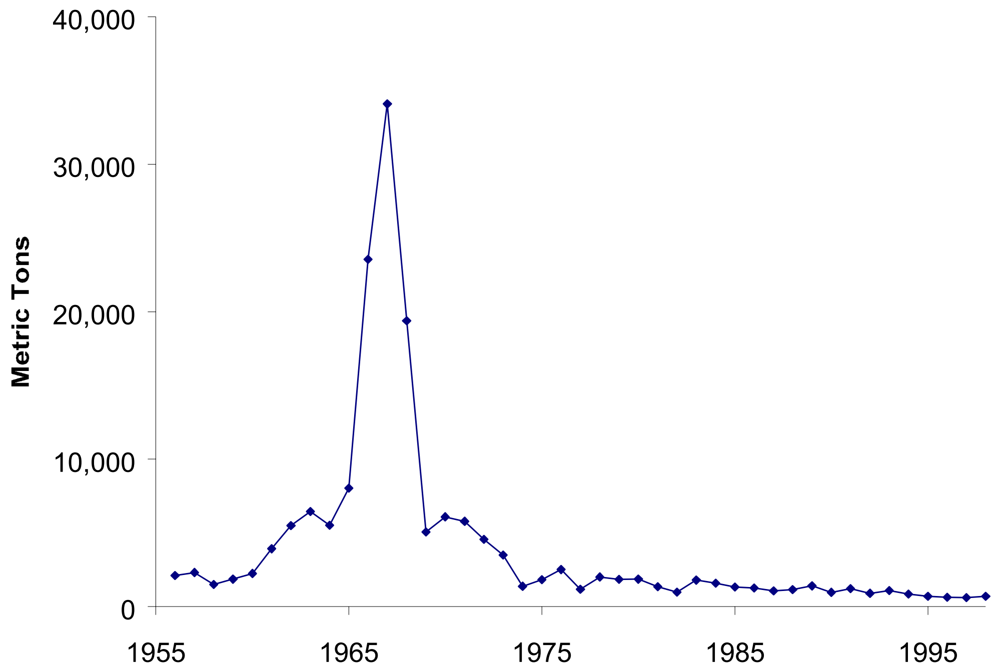


Figure 2. Pacific ocean perch catch including domestic and foreign fleets.

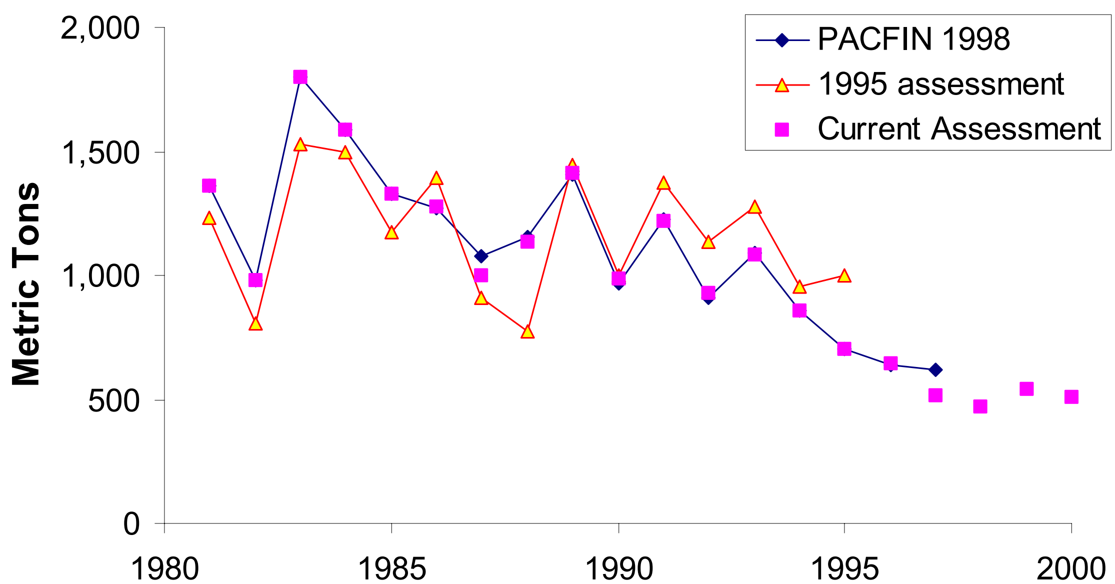


Figure 3. POP Catch estimates from the 1995 assessment compared with updated PACFIN estimates used in the current assessment.

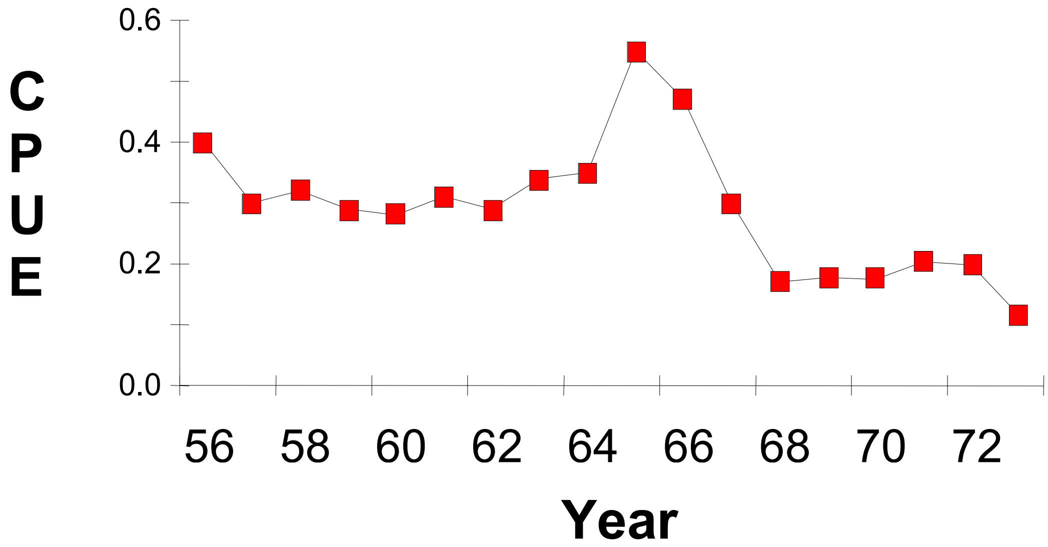


Figure 4. Pacific ocean perch catch per unit of effort data for the combined domestic fishery off INPFC area US- Vancouver and Columbia.

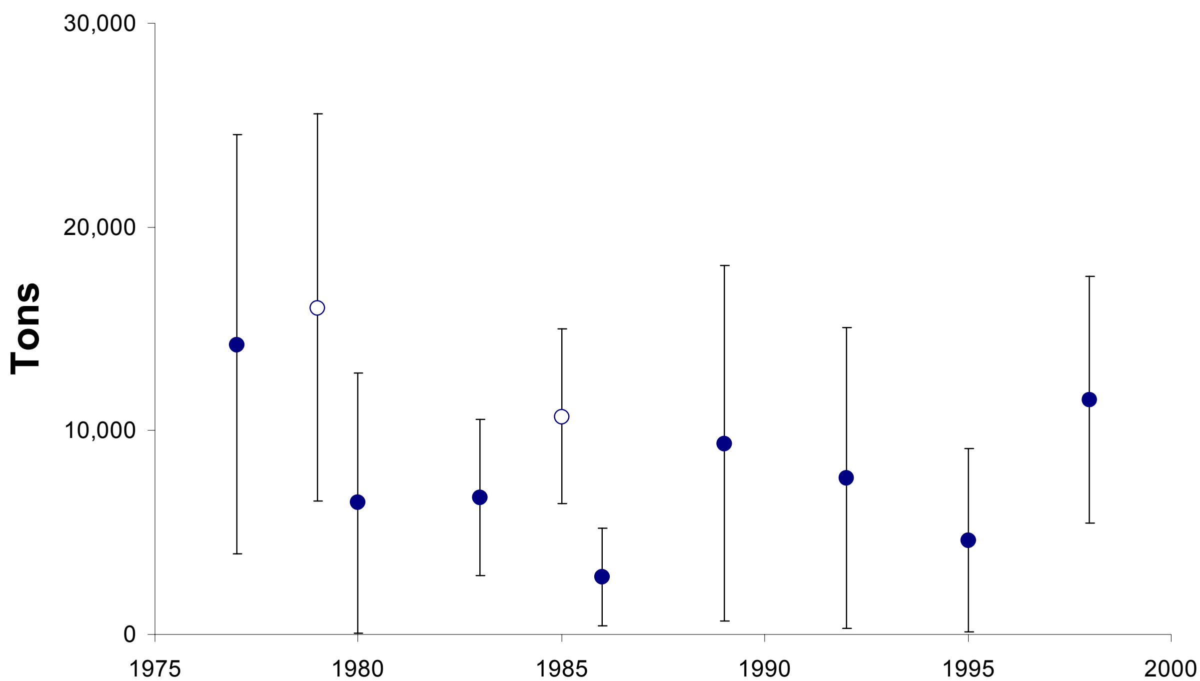
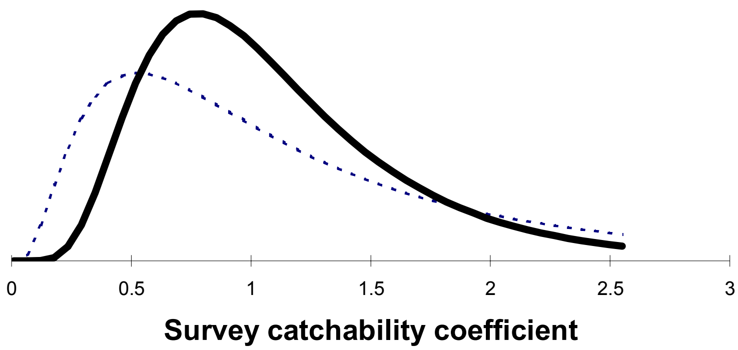


Figure 5. Survey biomass estimates and 95% confidence bounds for Pacific ocean perch. Open circles represent rockfish survey values and dark circles represent triennial survey biomass estimates.



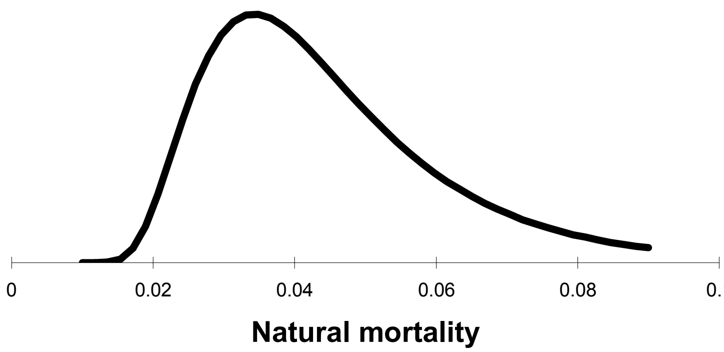


Figure 6. Plot showing the prior distributions assumed for survey catchability, and M. Dashed lines represent the priors used in Models 1b and 2b.

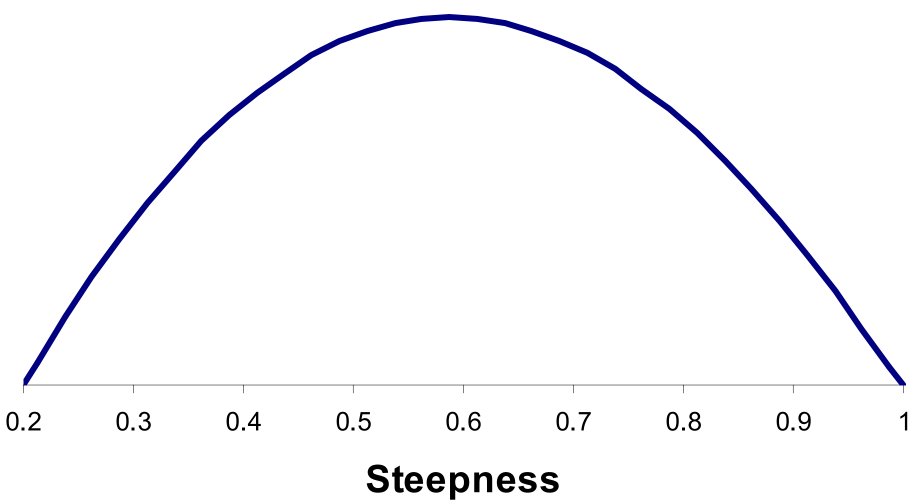


Figure 7. Steepness prior distribution assumed for Model 1c based on Dorn's (2000) combined meta-analysis (Ricker and Beverton Holt) with Beta distribution parameters α=2.01 and β=2.07.

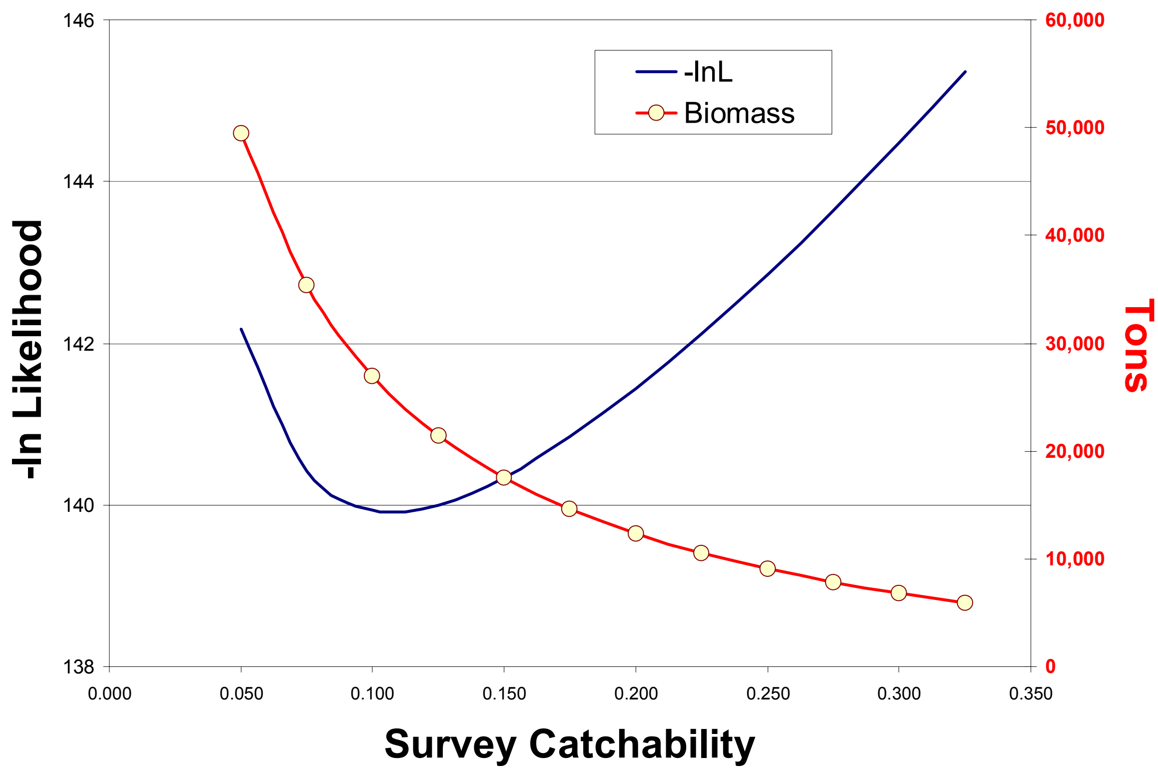


Figure 8. Plot showing the negative log-likelihood profile for different fixed values of survey catchability and the affect on year 2000 biomass levels (no prior).

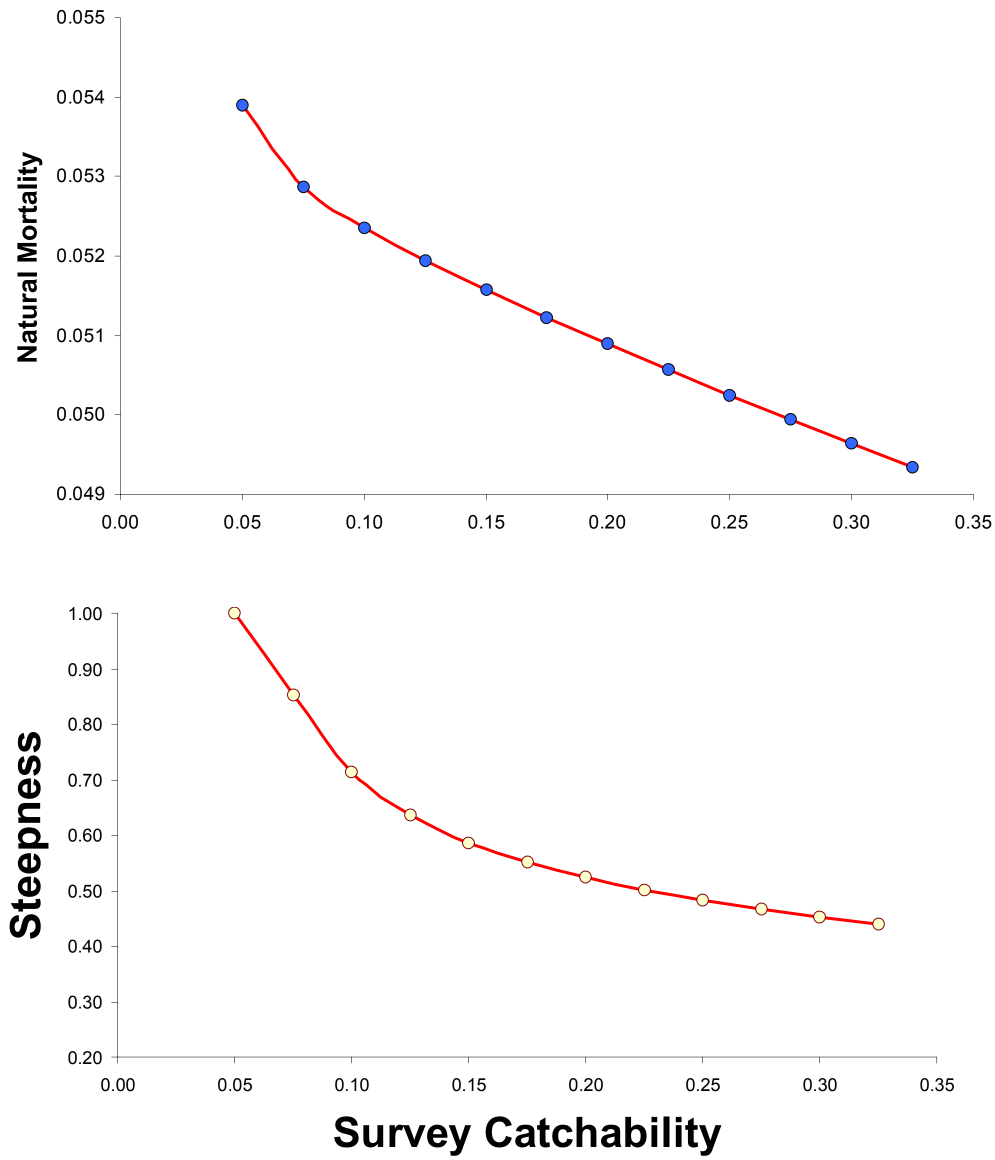


Figure 9. Plot showing the relationship between survey catchability and natural mortality (top panel) and stock-recruitment steepness (lower panel). These were computed as conditioned for different fixed values of survey catchability.

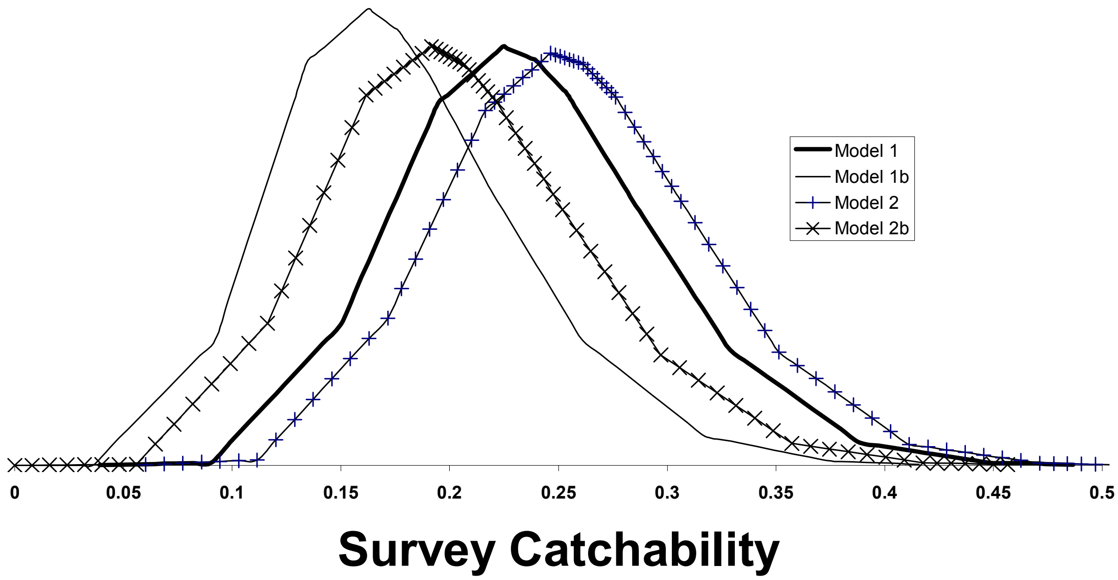


Figure 10. Plot showing the relative probability for alternative values of survey catchability, Models 1, 1b, 2, 2b.

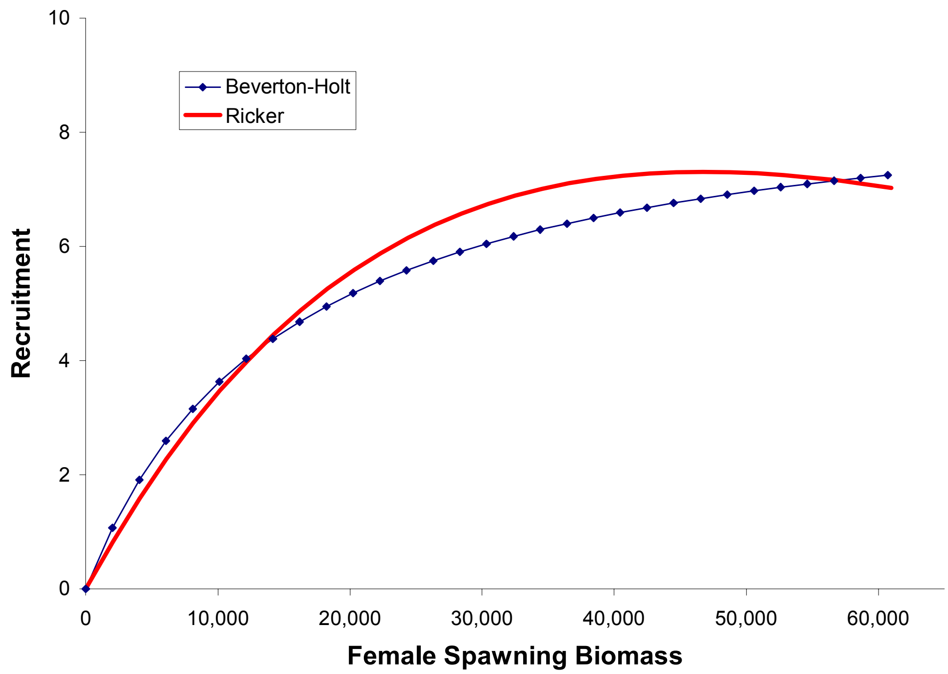


Figure 11. Estimated curves for the Beverton Holt (Model 1c) and for the Ricker (Model 1e).

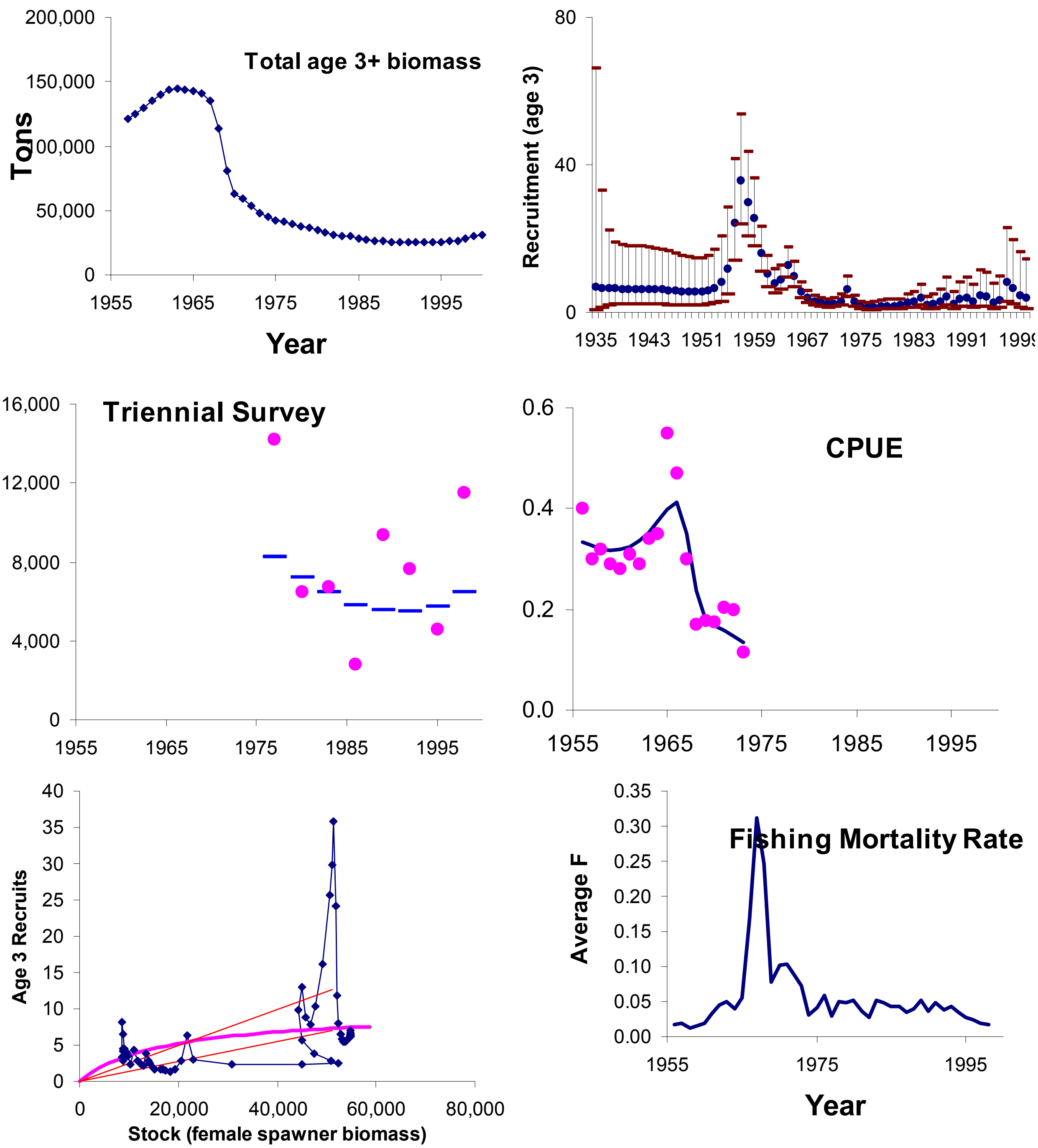


Figure 12. Summary of Model 1c results for Pacific ocean perch.

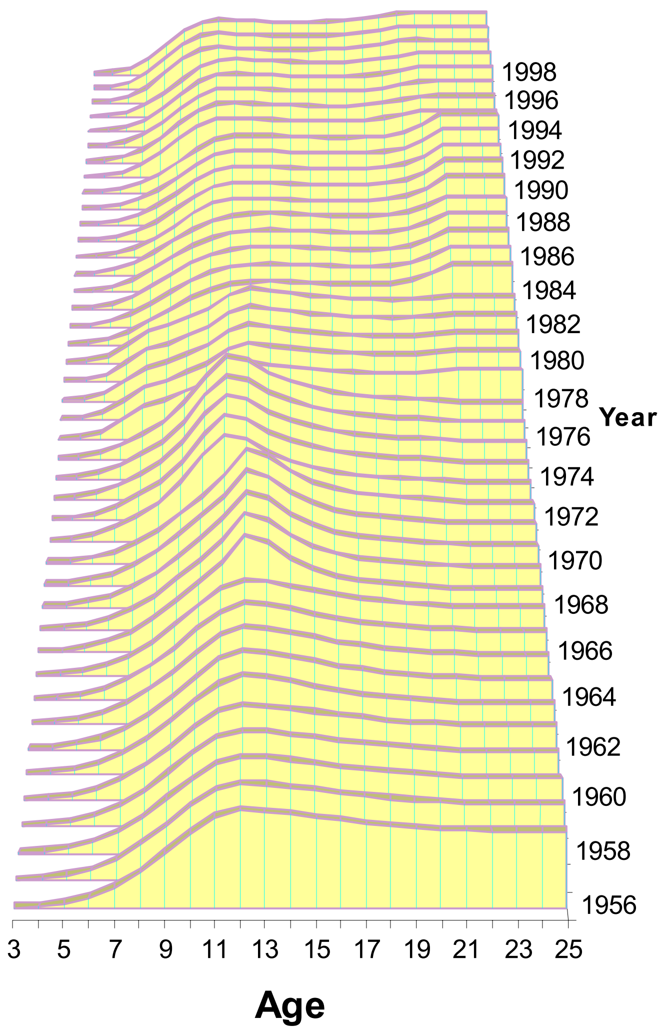


Figure 13. Fishery selectivity estimates for Pacific ocean perch, 1956-2000 for Model 1c.

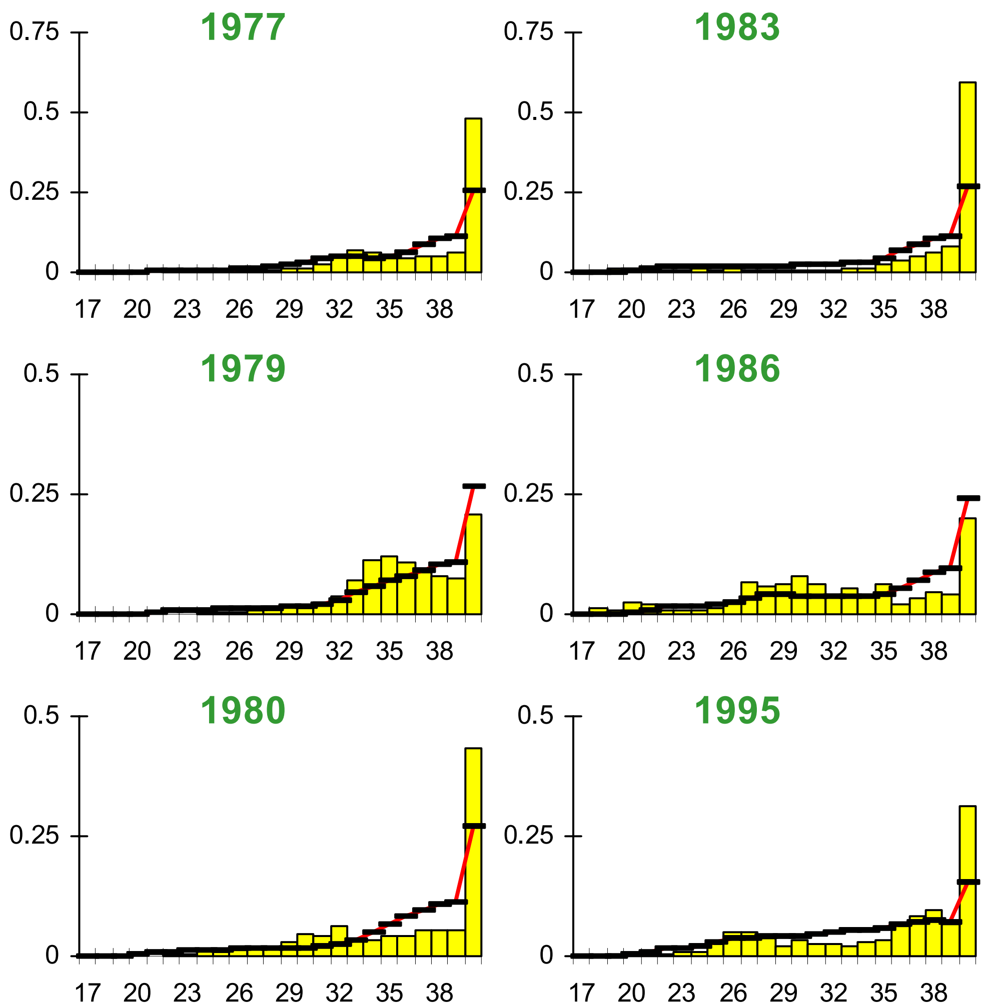


Figure 14. Predicted POP proportions-at-size (lines) relative to observed values (bars) for the “rockfish” and triennial survey data (Model 1c). Length is in cm.

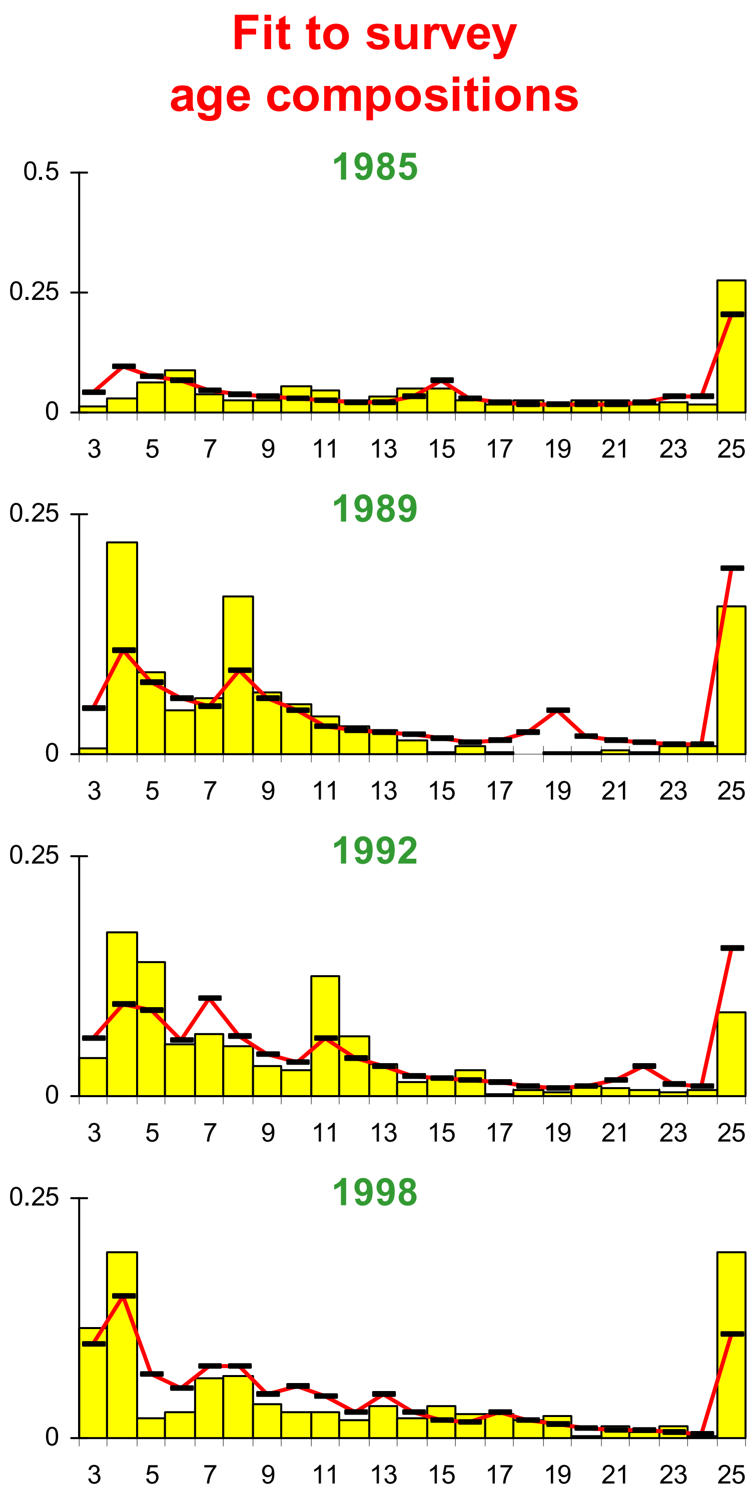


Figure 15. Predicted POP proportions-at-age (lines) relative to observed values (bars) for the “rockfish” and triennial survey data (Model 1c).

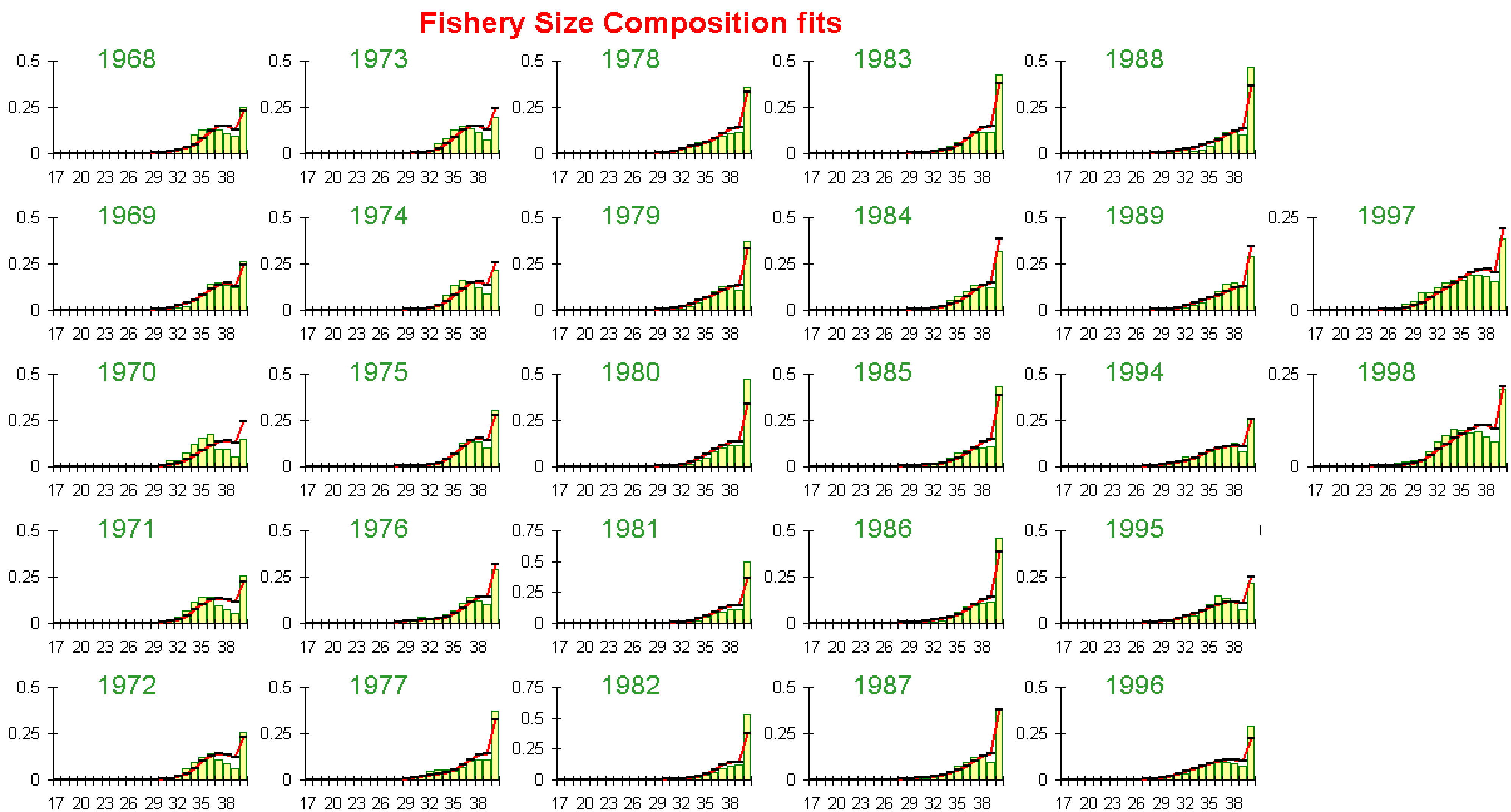


Figure 16. Predicted POP proportions-at-length (lines) relative to observed values (bars) for aggregate fisheries data (Model 1c).

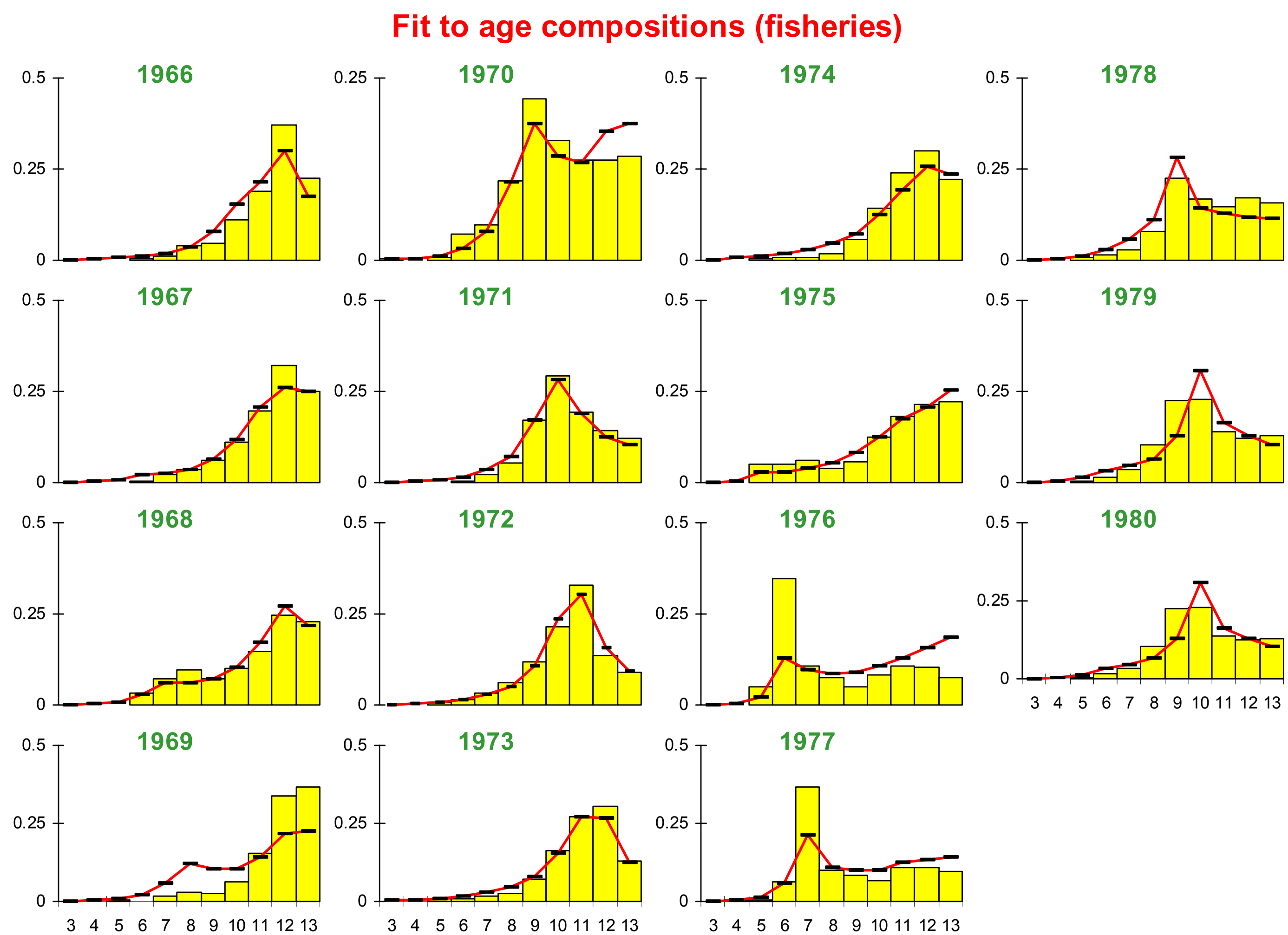


Figure 17. Predicted POP proportions-at-age (lines) relative to observed values (bars) for aggregate fisheries data (Model 1c).

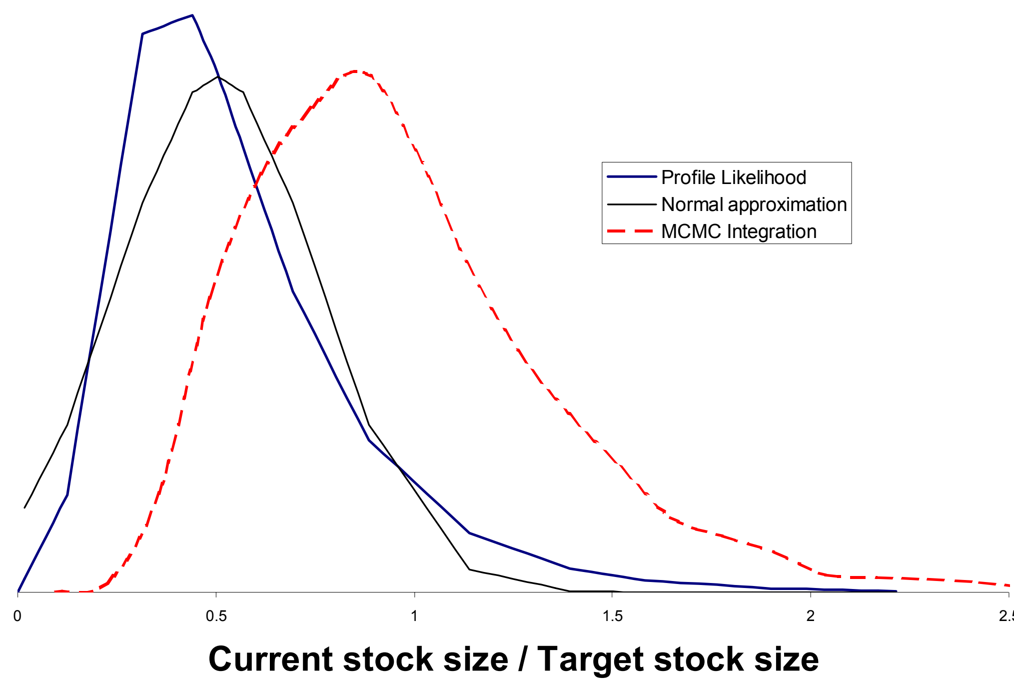


Figure 18. Relative marginal probability distributions of year 2000 stock size relative to B_{msy} using three different methods for Model 1c. Note that the normal and profile likelihood methods are approximations, and that the MCMC represents the correct marginal (provided the chain has converged to the true posterior distribution).

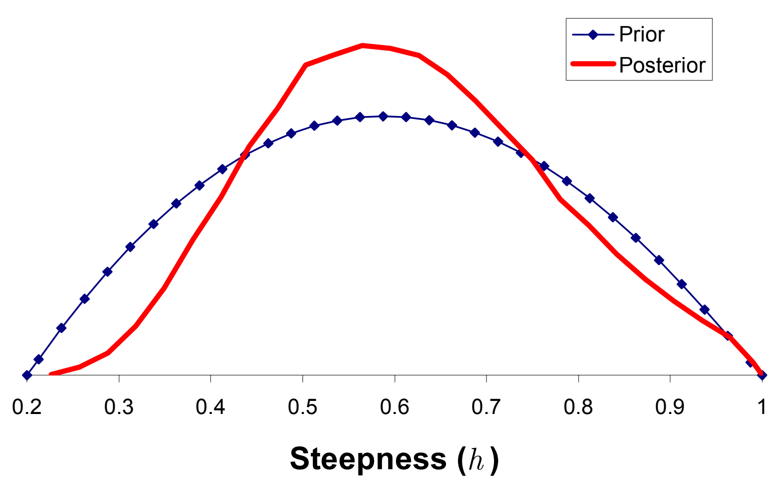


Figure 19. Marginal posterior probability distributions of Model 1c steepness (h) compared to the prior distribution assumed from Dorn 2000. The posterior mean value is 0.61 compared to the prior mean value of 0.59.

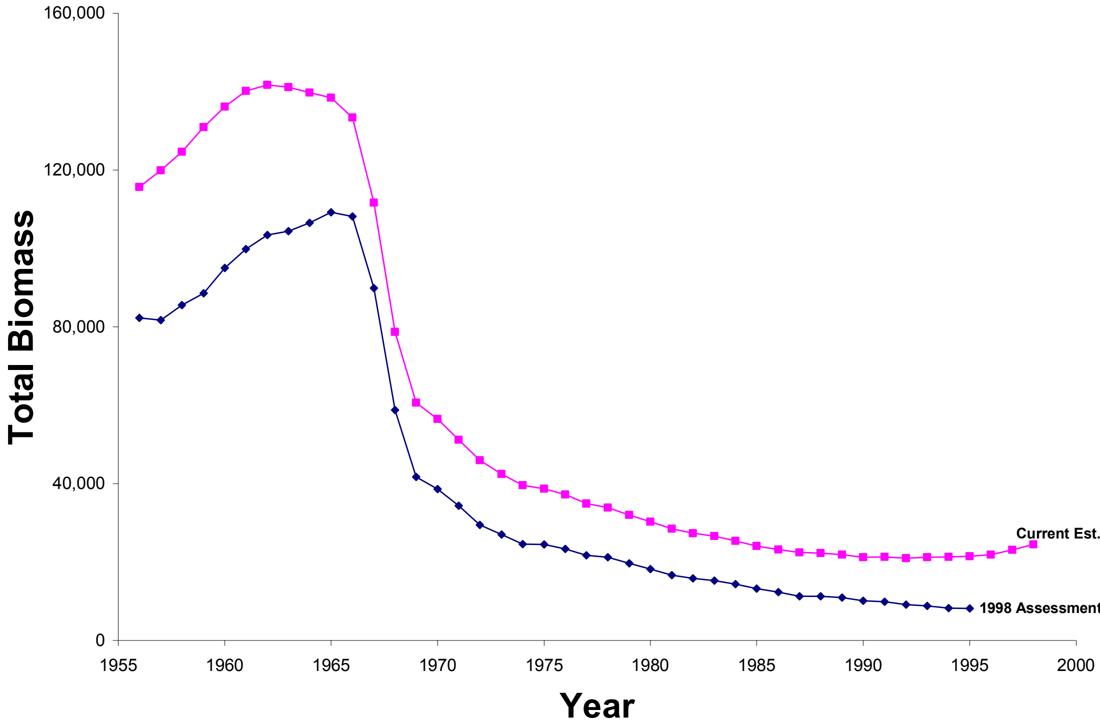


Figure 20. Age 3+ biomass comparing the current assessment with that of 1998.

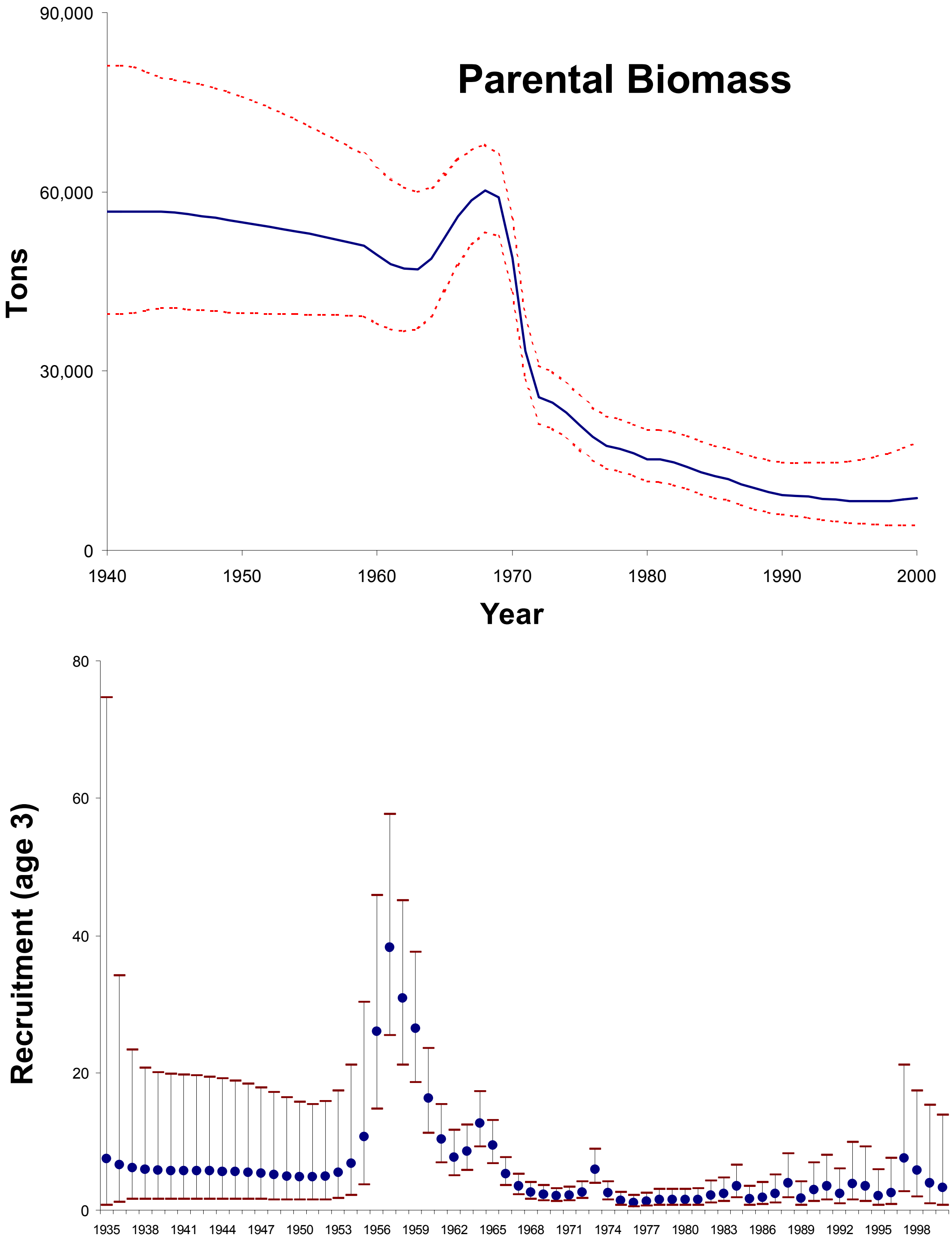


Figure 21. Parental biomass (female spawning biomass) and recruitment and the estimated 95% confidence bounds over time for Model 1c.

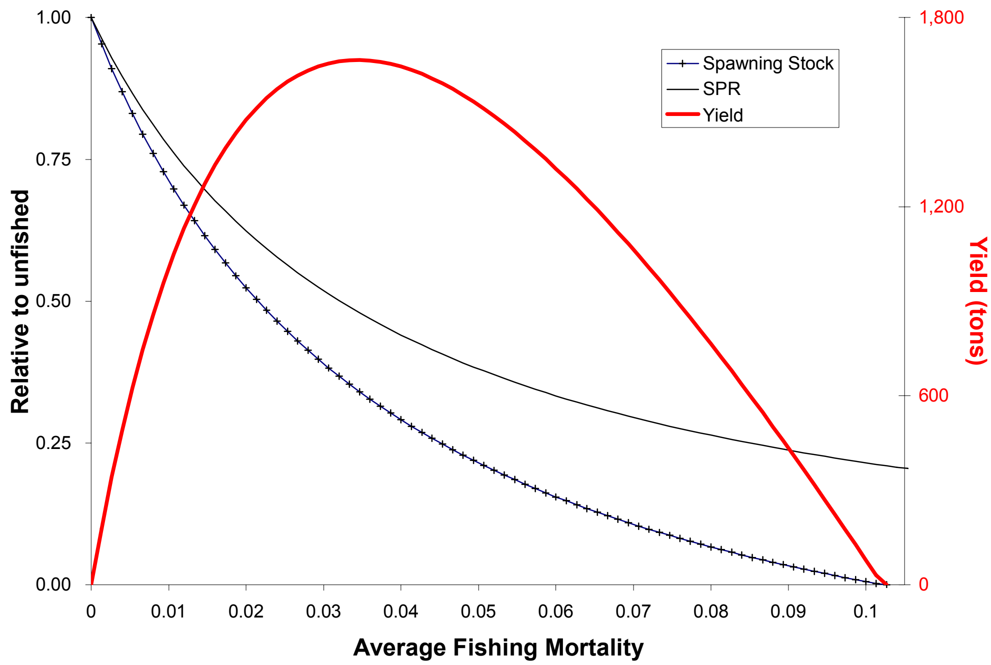


Figure 22. Equilibrium yield curve for the current Model 1c assessment relative to unfished spawning stock size (stock) and unfished spawning biomass per recruit (SPR).

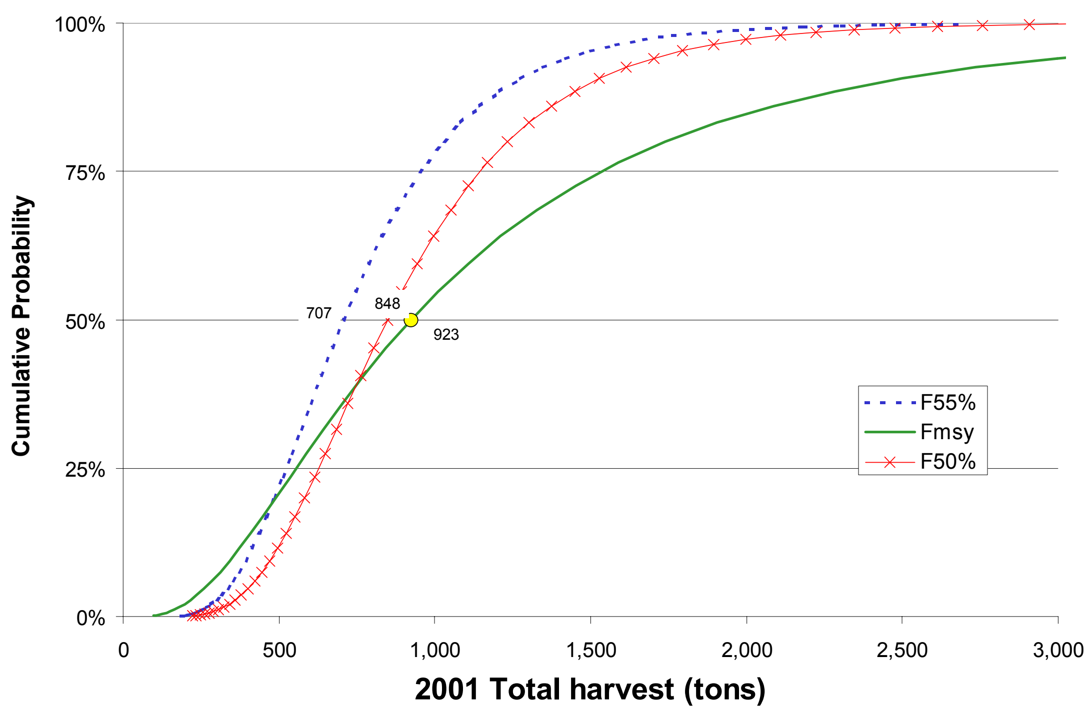


Figure 23. Projected cumulative probability curves for different harvest rates for POP in the year 2001 for Model 1c.

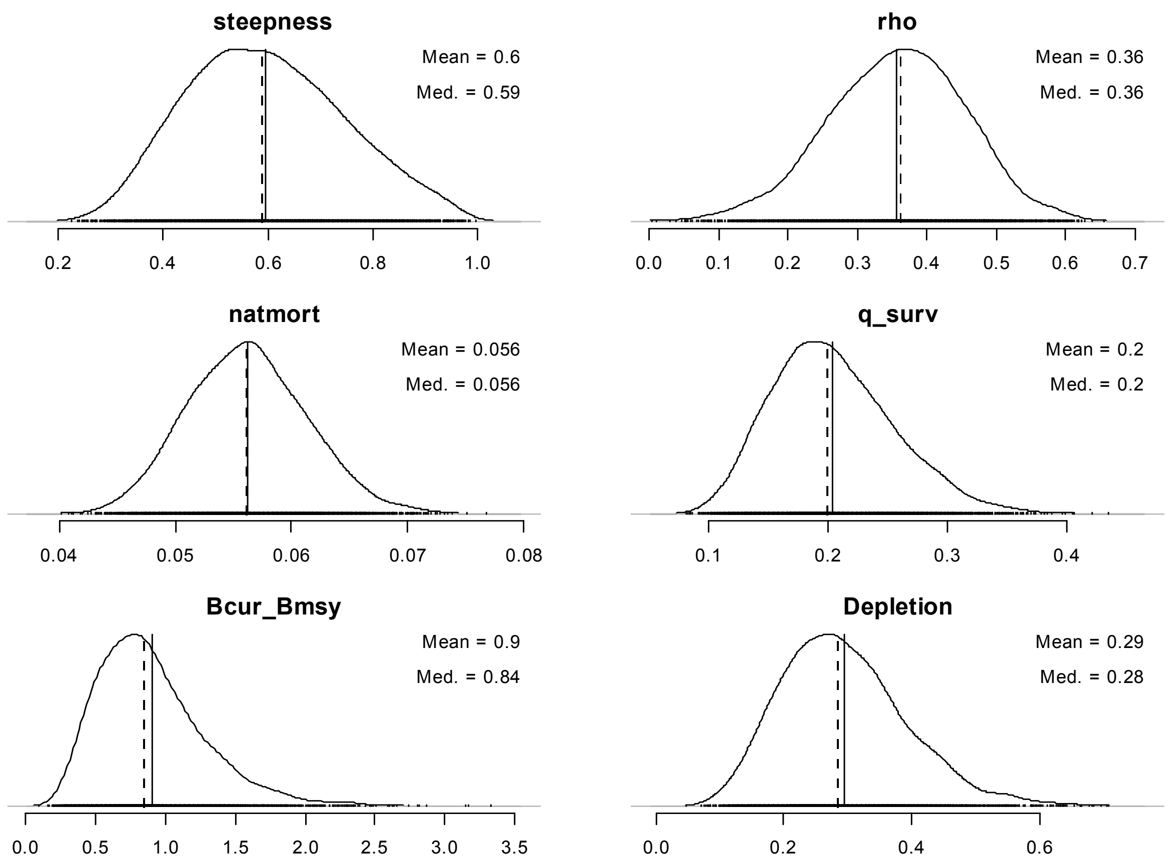


Figure 24. Estimated probability distributions for key parameters of interest from the reference case Model 1c. MCMC integration was used to obtain this marginal distribution (Gilks *et al.* 1996).

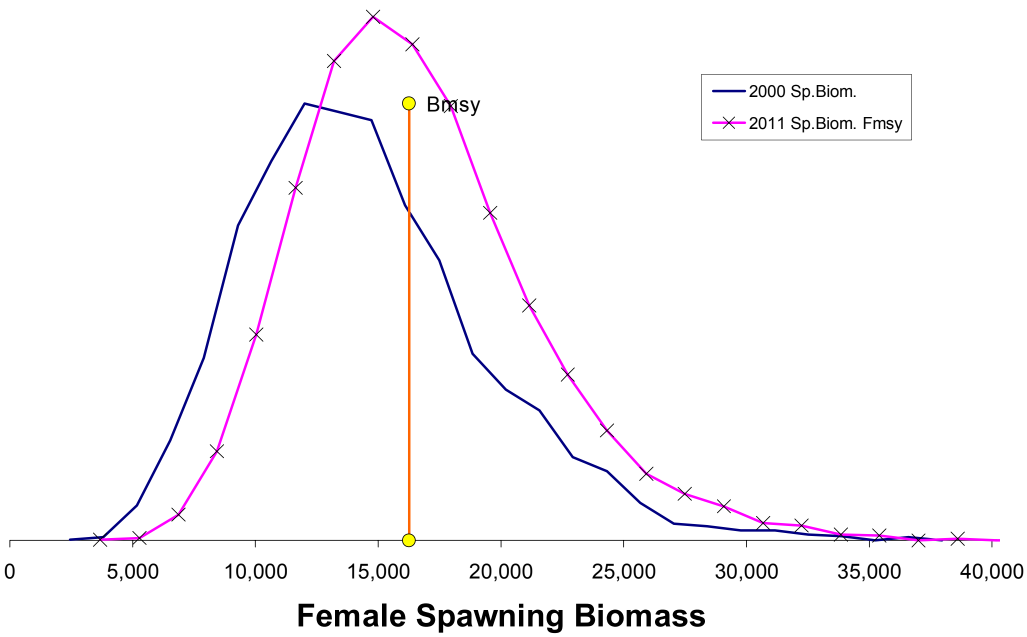


Figure 25. Probability distributions of projected POP female spawning biomass in the year 2011 under F_{msy} harvest compared to the year 2000 estimates for Model 1c. Vertical line represents the expected value for B_{msy} .

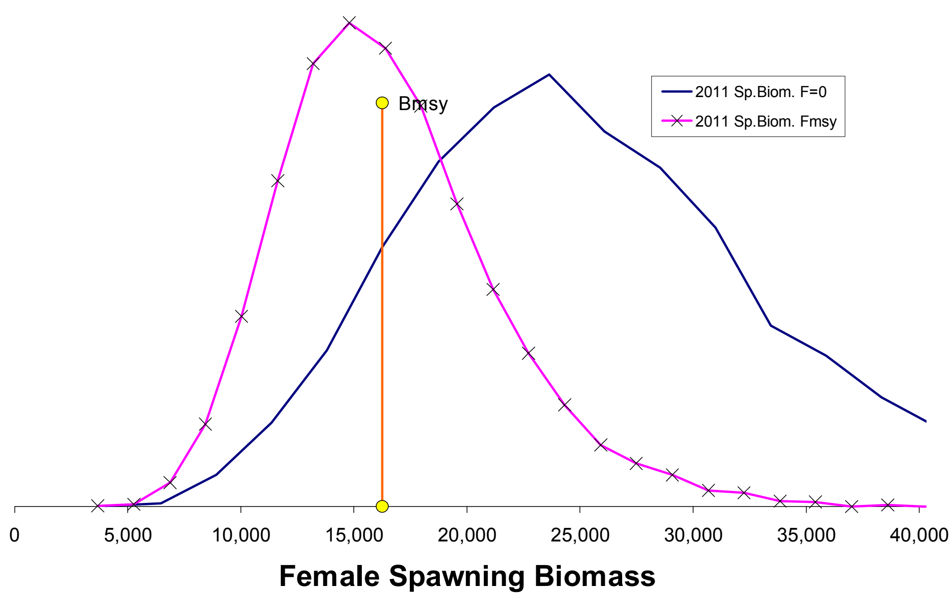


Figure 26. Probability distributions of projected POP female spawning biomass in the year 2011 under F_{MSY} harvest compared to no fishing (F=0) for Model 1c. Vertical line is expected value for B_{msy} .